92-e63

# IMPACTS OF EASTERN STATE HOSPITAL AND LAKELAND VILLAGE WASTEWATER DISCHARGES ON THE QUALITY OF WEST MEDICAL LAKE


by
Roger Willms
Greg Pelletier

Washington State Department of Ecology
Environmental Investigations and Laboratory Services Program
Watershed Assessments Section
Olympia, Washington 98504-7710


Water Body No. WA-43-9160
(Segment No. 19-43-101)

March 1992

TABLE OF CONTENTS

ABSTRACT

Limited Class II Inspections and receiving water surveys were conducted at the Eastern State Hospital and Lakeland Village Wastewater Treatment Plants (WTPs) on August 28-29 and October 30-31, 1990. Objectives of the study were to determine WTP efficiency and assess impacts of effluent discharge on West Medical Lake. In general, effluent quality was poorer at the Eastern State Hospital WTP. This plant was approaching its permit limits for biochemical oxygen demand and total suspended solids. Fecal coliform permit limits were exceeded in five of six effluent samples collected. Results of lake water quality determinations indicated extreme nutrient enrichment and hypereutrophic status. High fecal coliform levels were found in lake samples near the Eastern State Hospital outfall. A water budget indicated that effluent wastewater accounted for 51 percent of total inflows to the lake. Approximately 89 percent of the total phosphorus external load was a result of WTP discharges. In-lake nutrient recycling was also found to be significant. Nutrient modeling indicated that phosphorus controls for both external and internal loading would be needed to enhance the lake from its current hypereutrophic state to a eutrophic status. Lake management alternatives were explored and several recommendations suggested.

## ACKNOWLEDGEMENTS

Thanks are extended to Patricia Hervieux (Ecology Solid and Hazardous Waste Program) for assisting during the field surveys. Ken Merrill, Don Nichols, and Jim Prudente (Ecology Eastern Regional Office) provided valuable assistance during the WTP Inspection. Steve Holden (Consolidated Support Services) provided logistical support and invaluable lake stage and withdrawal data. Julie Rector (Ecology Ambient Monitoring Section) provided additional lake water quality data. Appreciation is extended to the following individuals for reviewing this report: Joe Joy, Will Kendra, Julie Rector, (Ecology Environmental Investigations and Laboratory Services Program); Lisa Humphreys, (Ecology Eastern Regional Office). Manuscript typing and editing were provided by Kim Douglas and Barbara Tovrea.

## INTRODUCTION

West Medical Lake is located in Spokane County, 1.2 miles southwest of Medical Lake, Washington. The lake is the receiving water for two state hospital wastewater treatment plants (WTPs). The Lakeland Village WTP (Plant 1) is regulated by National Pollutant Discharge Elimination System (NPDES) Permit No. WA-004487-3, issued October 23, 1990. Effluent enters the lake from a submerged outfall at the southwest end (Figure 1). The Eastern State Hospital WTP (Plant 2) is regulated by NPDES Permit No. WA-004486-5, issued October 23, 1990. Effluent enters the lake from an exposed pipe on the bank on the southeast shoreline (Figure 1). Both WTPs provide primary and secondary clarification, trickling filtration, and chlorination.

West Medical Lake drains an area of 4.7 $km^2$. Land use based on a 1973 survey (Dion, et al., 1976) is primarily agricultural (59%) and forested or unproductive (21%). The land surrounding the lake is state owned with no nearshore residential development. Lake characteristics include a surface area of 890,000 $m^2$, volume of 6,044,000 $m^3$, mean depth of 6.7 meters, and maximum depth of 8.5 meters (Figure 1). The lake has no natural surface-water inflow or outflow, resulting in a hydraulic residence time of about 29 years. Basin geology is primarily basalt and metamorphic rock and soil type is dominated by silt and stony silt loam.

Chapter 173-201-045 of the Washington Administrative Code (WAC) states that lake water quality shall meet or exceed the requirements for all characteristic uses. These uses include: water supply (domestic, industrial, agricultural), stock watering, fish and wildlife habitat, and recreation (primary contact, sport fishing, and aesthetic enjoyment). Currently, the primary uses of West Medical Lake are irrigation, livestock watering, sport fishing, boating, and wildlife habitat. A private resort and public boat launch are located at the south end.

West Medical Lake is in a highly eutrophic state, experiencing dense algal blooms and hypolimnetic anoxia during summer months. Nutrient levels are extremely high, with total phosphorus levels often exceeding 2 mg/L in the epilimnion, making it one of the most highly enriched lakes in the state.

The Washington State Department of Wildlife (WDW) manages West Medical Lake as a trout fishery and maintains aerators to prevent fish kills during summer and winter months. The nutrient rich lake supports abundant invertebrate and aquatic insect life resulting in impressive trout growth. As a result, West Medical is one of the more popular fisheries in the Spokane area. Prior to the installation of aerators, the lake could not consistently support a cold water fishery.

Ecology's Eastern Regional Office is concerned about excessive organic loading and water quality impacts from wastewater discharge and is considering permit modifications for plant upgrade, replacement with new plants, or removal of discharge from the lake. Consequently,

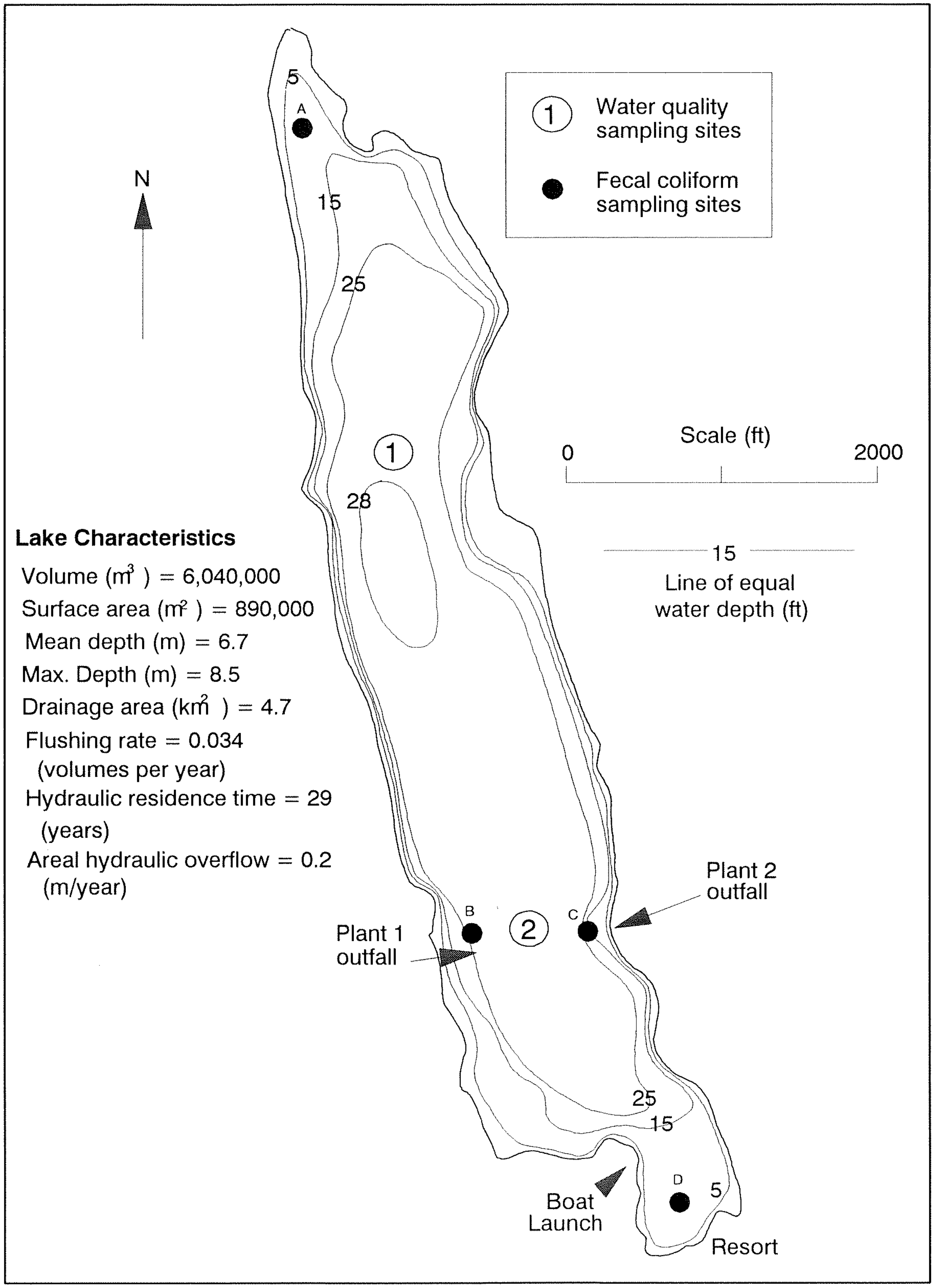



Figure 1. Map of West Medical Lake showing sampling sites. Bathymetric contours digitized from the Dion et al., 1976. The maximum depth contour was modified by sonar measurements made during this study.

the Watershed Assessments Section (WAS) of Ecology was asked to conduct a study to evaluate water quality impacts associated with the discharges. Study objectives were as follows:

1. determine water quality impacts on West Medical Lake from wastewater discharges;

2. evaluate removal efficiency and permit compliance of both WTPs; and

3. recommend permit modifications to improve the effectiveness of the WTPs and protect/enhance the quality of West Medical Lake.

## METHODS

Intensive surveys were conducted on August 28-29 and October 30-31, 1990. Sampling sites included 2 mid-lake stations, 4 shoreline areas, and influent and effluent at both WTPs (Figure 1). Additional lake water quality data for May 23, 1990, was acquired from Ecology's Ambient Monitoring Section (AMS). Sampling parameters and frequency are listed in Tables 1 and 2.

Influent and effluent composite and effluent grab samples were collected on August 28-29 and October 30-31 at both WTPs. Influent flows were measured at the Parshall flume and influent samples were collected directly downstream of the Parshall flume at both plants. At Plant 1, effluent composite samples were collected at the final clarifying pond and effluent grabs were collected at the manhole near the lake. At Plant 2, effluent composite and grab samples were collected at the small earthen holding pond downstream of the chlorine contact chamber. ISCO® sampling compositors collected 200 mL every half-hour over a 24-hour period. Composite samples collected by Ecology and composite samples collected by the WTP operators were split to compare $BOD_5$ and TSS results. Total residual chlorine (TRC) was determined on site using a LaMotte-Palin DPD test kit. To better assess variability in nutrient loading, additional total phosphorus (TP) and total nitrogen (TN) effluent samples were collected on three occasions by the WTP operators between August 30 and October 30, 1990.

At the two lake stations, a Hydrolab Surveyor II water quality instrument was used to measure temperature, conductivity, pH, and dissolved oxygen at one meter intervals from surface to bottom. Water samples for laboratory analysis were collected with a Kemmerer bottle at five depths from surface to bottom. Fecal coliform samples were taken by hand below the water surface. Total residual chlorine was measured with a ULR Chemets chlorine kit. Secchi disk measurements were taken at both sites to assess water clarity. Chlorophyll *a* samples were collected at surface, three, and six meter depths. Phytoplankton samples were taken by compositing equal volumes from surface, two, and four meter depths. Vertical zooplankton tows were taken from bottom to surface with a Wisconsin style plankton net. Phytoplankton samples were analyzed by Aquatic Analysts, Portland, Oregon. Zooplankton were analyzed by Arnie Litt, University of Washington, Department of Zoology.

Table 1. Sampling design and schedule for West Medical Lake water quality surveys.

| | Site 1 | | | | | | | | | Site 2 | | | | | | | | | Shoreline Areas | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depth | | | | | | | | | Depth | | | | | | | | | | | | |
| PARAMETERS | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | A | B | C | D |
| Secchi Disk | M,A,O | - | - | - | - | - | - | - | - | M,A,O | - | - | - | - | - | - | - | - | - | - | - | - |
| Temperature | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | - | - | - | - |
| Dissolved Oxygen | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | - | - | - | - |
| pH | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | - | - | - | - |
| Conductivity | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | M,A,O | - | - | - | - |
| Total Residual Chlorine | A,O | - | - | - | - | - | - | - | - | A,O | - | - | - | - | - | - | - | - | - | O | A,O | - |
| Fecal Coliform | - | - | - | - | - | - | - | - | - | A | - | - | - | - | - | - | - | - | A,O | A,O | A,O | A,O |
| Alkalinity | A,O | - | - | A,O | - | A,O | - | A,O | A,O | A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Total Phosphorus | M,A,O | - | - | A,O | - | A,O | - | A,O | A,O | M,A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Soluble Reactive Phosphorus | A,O | - | - | A,O | - | A,O | - | A,O | A,O | A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Total Nitrogen | M,A,O | - | - | A,O | - | A,O | - | A,O | A,O | M,A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Ammonia Nitrogen | A,O | - | - | A,O | - | A,O | - | A,O | A,O | A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Nitrate+Nitrite Nitrogen | A,O | - | - | A,O | - | A,O | - | A,O | A,O | A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Total Organic Carbon | A,O | - | - | A,O | - | A,O | - | A,O | A,O | A,O | - | - | A,O | - | A,O | - | A,O | A,O | - | - | - | - |
| Chlorophyll a | A,O | - | - | A,O | - | - | A,O | - | - | A,O | - | - | A,O | - | - | A,O | - | - | - | - | - | - |
| Phytoplankton Biovolume | A,O (composite 0,2, and 4 meters) | | | | | | | | | A,O (composite 0, 2, and 4 meters) | | | | | | | | | - | - | - | - |
| Zooplankton | A,O (vertical tow from 8 meters to surface) | | | | | | | | | A,O (vertical tow from 8 meters to surface) | | | | | | | | | - | - | - | - |

M = May 23

A = Aug 28

O = Oct 30

Table 2. Sampling schedule for West Medical Lake limited Class II inspections August 28-29 and October 30-31, 1990.

| Sample Type | Date | Time | Flow | Temp. | D.O. | pH | Cond | TRC | FC | TSS | BOD-5 | TOC | TP | TN | NH3-N | NO3+NO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant 1 | | | | | | | | | | | | | | | | |
| Influent Comp. | 8/29/90 | 0900 | - | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Comp. | 8/29/90 | 0915 | X | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Grab | 8/28/90 | 1030 | X | X | X | X | X | X | - | - | - | - | - | - | - | - |
| | 8/29/90 | 0825 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Effluent Comp. | 9/8/90 | 1000 | X | - | - | - | - | - | - | - | - | - | X | X | - | - |
| | 9/22/90 | 1100 | X | - | - | - | - | - | - | - | - | - | X | X | - | - |
| | 10/4/90 | 1230 | X | - | - | - | - | - | - | - | - | - | X | X | - | - |
| Influent Comp. | 10/31/90 | 0945 | - | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Comp. | 10/31/90 | 1000 | X | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Grab | 10/30/90 | 1100 | X | X | X | X | X | X | X | - | - | - | - | - | - | - |
| | 10/31/90 | 1215 | - | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Plant 2 | | | | | | | | | | | | | | | | |
| Influent Comp. | 8/29/90 | 1055 | - | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Comp. | 8/29/90 | 1040 | X | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Grab | 8/28/90 | 0900 | X | X | X | X | X | X | X | - | - | - | - | - | - | - |
| | 8/29/90 | 1000 | - | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Effluent Comp. | 9/8/90 | 0920 | X | - | - | - | - | - | - | - | - | - | X | X | - | - |
| | 9/22/90 | 1045 | X | - | - | - | - | - | - | - | - | - | X | X | - | - |
| | 10/5/90 | 0800 | X | - | - | - | - | - | - | - | - | - | X | X | - | - |
| Influent Comp. | 10/31/90 | 0900 | - | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Comp. | 10/31/90 | 0915 | X | - | - | - | - | - | - | X | X | X | X | X | X | X |
| Effluent Grab | 10/30/90 | 0840 | X | X | X | X | X | X | - | - | - | - | - | - | - | - |
| | 10/31/90 | 0820 | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

– = no sample or measurement taken.
X = sample or measurement taken.

Samples for lab analysis were stored on ice and shipped to arrive at the Ecology/Environmental Protection Agency (EPA) Laboratory in Manchester, Washington, within 24 hours of sample collection. All laboratory analyses were performed in accordance with EPA (1983), APHA *et al.*, (1989), and Huntamer and Smith (1989). The WTP labs also ran split samples of selected parameters.

Approximately 15 percent of all lab samples were quality assurance related. Field replicates were used to assess field and laboratory variability and blanks were used to evaluate detection limits. Field instruments were calibrated each morning and post-calibrated at the end of each survey.

The following steady-state equation (Reckhow and Chapra, 1983) was used to solve for various nutrient loading scenarios for West Medical Lake:

$$(1) \qquad P = \frac{W}{v_s A_s + Q_{out}} = \frac{L}{v_s + q_s}$$

where:

$P$ = steady-state whole lake total P or total N ($mg/m^3$)
$W$ = total P or N load (mg/year)
$v_s$ = settling velocity (m/year)
$A_s$ = lake surface area ($m^2$)
$Q_{out}$ = lake outflow corrected for storage ($m^3$/year)
$L$ = areal load of P or N ($mg/m^2$/year)
$q_s$ = areal hydraulic overflow (m/year).

Equation 1 can be modified when internal sediment feedback of nutrients is significant. The appropriate mass balance equation with sediment feedback is (Reckhow and Chapra, 1983):

$$(2) \qquad P = \frac{L}{(fv_s + q_s)}$$

which is similar to (1) except for the dimensionless sediment feedback factor "f" which represents the fraction sedimented P which is buried in the deep sediments and unavailable for internal loading. Equation (2) may be rearranged to estimate $fv_s$ for existing conditions:

$$(3) \qquad fv_s = (L/P) - q_s$$

The value of "f" can be estimated by assuming typical values of $v_s$ reported in the literature for lakes with negligible sediment feedback and then solving equation 3 for "f." Typical values of $v_s$ are reported to be approximately 12 m/year for total P and 10 m/year for total N with an approximate range of $\pm$30 percent (Mancini *et al.*, 1983; Reckhow and Chapra, 1983).

The time required for lake nutrient concentrations to show improvement with reduced loading can be estimated from (Chapra and Reckhow, 1983):

(4) $t_{90} = 2.3\,(V/(Q_{out} + fv_s\,V))$

where V is lake volume ($m^3$) and $t_{90}$ represents the time (years) for the lake concentration to reach 90 percent of a new steady state level.

A first-order error propagation methodology was used to evaluate the uncertainty associated with modeling errors, as described by Reckhow and Chapra (1983). Since the model used in this study is based on discharge and chemical measurements, a variety of potential modeling and measurement errors contribute to the total uncertainty of a given prediction. The statistical technique used is based on the assumption that parameter variations can be propagated about the first derivative of a function relative to those variables which make up the function. Parameter estimates are presented as mean values plus or minus the standard error of the mean unless otherwise stated.

## RESULTS AND DISCUSSION

### Data Quality Assessment

Data which did not meet internal laboratory quality assurance (QA) guidelines are flagged in the data tables. An external quality assurance program was conducted by submitting a series of field replicates and blanks to the laboratory. Replicate pairs were compared by calculating the relative percent difference (RPD), defined as the difference between two replicates expressed as a percentage of their mean. These data are provided below. In general, RPDs for replicate pairs showed low variability. The exception was one of two fecal coliform replicates, with a RPD of 65 percent. This variability is not uncommon for fecal coliform distributions which are patchy by nature. Blank results were near detection limits for all parameters (Appendix B).

| Parameter | No. Repl. Pairs | RPD Range (%) | Average RPD (%) |
|---|---|---|---|
| Fecal coliform | 2 | 10-67 | 37.5 |
| TSS | 2 | 17-24 | 20.5 |
| $BOD_5$ | 1 | - | 3.0 |
| TOC | 4 | 1-11 | 5.8 |
| Alkalinity | 2 | 0.3-3 | 1.7 |
| TP | 4 | 1.4-9.4 | 4.6 |
| SRP | 4 | 0-5.4 | 2.7 |
| TN | 4 | 1-5.7 | 2.5 |
| NH3-N | 4 | 0-14.6 | 5.2 |
| NO3+NO2-N | 4 | 0-22.6 | 6.3 |

In reviewing the data it was observed that most ammonia results were greater than TN results for Plant 2 samples. While this is not desirable, lack of precision is fairly common in very concentrated samples which require numerous dilutions. Both ammonia and TN values for Plant 2 should be considered less precise than other nutrient results.

Limited Class II Inspections

A summary of data collected at both WTPs during each survey can be found in Appendix A. Table 3 provides a summary of effluent samples collected at both plants. Discharge measured at Plant 1 averaged 0.16 MGD for both surveys. At Plant 2, discharge was higher, averaging 0.20 MGD for the study. In general, effluent quality was poorest at Plant 2. Effluent fecal coliform, total suspended solids (TSS), 5-day biochemical oxygen demand ($BOD_5$), total organic carbon (TOC), total phosphorus (TP), total nitrogen (TN), and ammonia concentrations were considerably higher at Plant 2. At Plant 2, fecal coliform bacteria had a geometric mean of 816 colony forming units (cfu)/100 mL. Very little phosphorus removal was occurring at either plant. Plant 1 had good N removal in August. While effluent TP concentrations were similar at both plants, TN and ammonia concentrations were 3-6 times higher in Plant 2 effluent.

Split sample results for $BOD_5$ and TSS are illustrated in Figures 2 and 3. In general, samples split between Ecology's lab and both WTP labs were not very comparable. Split sample pairs were compared by calculating the RPDs. At Plant 1, the RPDs for $BOD_5$ ranged from 20 to 44 percent, with an average of 30 percent. TSS splits were not even comparable at Plant 1.

At Plant 2, RPDs for $BOD_5$ ranged from 7 percent to 35 percent, averaging 21 percent. TSS splits for Plant 2 were also not comparable. The levels of influent TSS measured by the WTP operators were far below those typically found in domestic wastewater (Metcalf and Eddy 1991), making their data questionable, especially when compared to the Ecology data. It appears that some major errors are occurring with their analytical procedures. A thorough review of laboratory methods for $BOD_5$ and TSS determination is in order. Both WTPs should be working towards lab accreditation if they plan on continuing their own analyses in the future.
Assessment of NPDES permit compliance during each survey for both WTPs is presented in Table 4. New NPDES permit limits were issued at both plants effective October 23, 1990. Notice that the new permit is less restrictive for several parameters, including $BOD_5$, TSS, total residual chlorine (TRC), and pH. At Plant 1, effluent composite concentrations for $BOD_5$ and TSS were well below permit limits on both surveys. Removal for both parameters ranged from 93 to 96 percent. The permit limit for fecal coliform was exceeded at Plant 1 for a single sample collected on October 30.

Plant 2 was approaching its new permit limits for $BOD_5$ and TSS concentrations during both surveys (Table 4). Removal efficiency for $BOD_5$ was 82 and 85 percent for August and October, respectively. For TSS, removal was 62 percent for August and 84 percent for October. Exceedance of the fecal coliform permit limit (weekly average of 40 cfu/100 mL) was measured in 5 of 6 samples collected at Plant 2 during August and October. Levels were very high with geometric means of 2,600 cfu/100 mL in August and 256 cfu/100 mL in October.

Table 3. Summary statistics for the Class II inspections at Plant 1 and Plant 2.
Statistics include all sampling events.

| Parameter | Units | N | Range | Mean | | Standard Dev. |
|---|---|---|---|---|---|---|
| PLANT 1 EFFLUENT | | | | | | |
| Grabs | | | | | | |
| Flow | MGD | 5 | 0.12–0.19 | 0.16 | | 0.02 |
| Temperature | °C | 5 | 10.0–17.9 | 14.6 | | 4.1 |
| pH | Std Units | 5 | 6.7–7.9 | 7.6 | * | – |
| Dissolved Oxygen | mg/L | 5 | 3.2–6.9 | 4.9 | | 1.8 |
| Dissolved Oxygen | % Saturation | 5 | 33–61 | 47 | | 12.9 |
| Total Residual Chlorine | mg/L | 5 | 0.3–1.0 | 0.7 | | 0.3 |
| Total Suspended Solids | mg/L | 3 | 5–7 | 6 | | 1 |
| Biochemical Oxygen Demand (5-day) | mg/L | 3 | 6–12 | 8 | | 3 |
| Total Organic Carbon | mg/L | 2 | 27.1–34.2 | 30.6 | | 5.0 |
| Fecal Coliform | CFU/100 mL | 4 | 2–13,100 | 23 | ** | – |
| Total P | mg/L | 2 | 4.80–6.59 | 5.24 | | 0.63 |
| Total N | mg/L | 2 | 2.15–5.69 | 3.92 | | 2.50 |
| Ammonia N | mg/L | 2 | 2.16–3.63 | 2.89 | | 1.04 |
| Nitrate + Nitrite N | mg/L | 2 | 0.058–1.920 | 0.989 | | 1.320 |
| Composites | | | | | | |
| Total Suspended Solids | mg/L | 2 | 5–6 | 6 | | 1 |
| Biochemical Oxygen Demand (5-day) | mg/L | 2 | 10–13 | 12 | | 2 |
| Total Organic Carbon | mg/L | 2 | 23.5–28.7 | 26.1 | | 3.7 |
| Total P | mg/L | 5 | 5.50–6.60 | 6.06 | | 0.45 |
| Total N | mg/L | 5 | 2.34–5.62 | 3.93 | | 1.39 |
| Ammonia N | mg/L | 2 | 1.70–3.96 | 2.83 | | 1.60 |
| Nitrate + Nitrite N | mg/L | 2 | 0.90–1.64 | 1.27 | | 0.52 |
| PLANT 2 EFFLUENT | | | | | | |
| Grabs | | | | | | |
| Flow | MGD | 5 | 0.19–0.23 | 0.20 | | 0.02 |
| Temperature | °C | 4 | 15.8–23.5 | 19.5 | | 4.0 |
| pH | Std Units | 4 | 7.1–7.4 | 7.4 | * | – |
| Dissolved Oxygen | mg/L | 4 | 0.0–0.4 | 0.2 | | 0.2 |
| Dissolved Oxygen | % Saturation | 4 | 0–4 | 2 | | 2 |
| Total Residual Chlorine | mg/L | 4 | – | 0.1 | U | – |
| Total Suspended Solids | mg/L | 2 | 25–30 | 27 | | 3 |
| Biochemical Oxygen Demand (5-day) | mg/L | 2 | 33–34 | 34 | | 1 |
| Total Organic Carbon | mg/L | 2 | 49.8–51.8 | 50.8 | | 1.0 |
| Fecal Coliform | CFU/100 mL | 4 | 7–18,700 | 816 | ** | – |
| Total P | mg/L | 2 | 4.90–6.18 | 5.54 | | 0.91 |
| Total N | mg/L | 2 | 12.00–15.79 | 13.85 | | 2.68 |
| Ammonia N | mg/L | 2 | 15.1–16.9 | 16.0 | | 1.3 |
| Nitrate + Nitrite N | mg/L | 2 | 0.055–0.750 | 0.402 | | 0.491 |
| Composites | | | | | | |
| Total Suspended Solids | mg/L | 2 | 36–38 | 37 | | 1 |
| Biochemical Oxygen Demand (5-day) | mg/L | 2 | 34–43 | 38 | | 6 |
| Total Organic Carbon | mg/L | 2 | 54.1–68.9 | 61.5 | | 10.5 |
| Total P | mg/L | 5 | 6.29–8.28 | 7.28 | | 0.82 |
| Total N | mg/L | 5 | 3.62–17.77 | 11.30 | | 5.61 |
| Ammonia N | mg/L | 2 | 17.9–18.6 | 18.3 | | 0.5 |
| Nitrate + Nitrite N | mg/L | 2 | 0.039–0.089 | 0.064 | | 0.035 |

* = median value

** = geometric mean

U = Analyte not detected. The value given is the sample detection limit.

Table 4. Assessment of NPDES permit compliance during the limited Class II inspections at WTPs 1 and 2 on West Medical Lake.

| Parameter | Units | NPDES Permit Limits Expired 10/22/90 Monthly Average | Weekly Average | NPDES Permit Limits Effective 10/23/90 Monthly Average | Weekly Average | August 28-29 Effluent Quality Grab | Composite | October 30-31 Effluent Quality Grab | Composite |
|---|---|---|---|---|---|---|---|---|---|
| PLANT 1 | | | | | | | | | |
| BOD5 | mg/L | 20 | 30 | 30 | 45 | - | 10 | - | 13 J |
| | lbs/day | 42 | 63 | 65 | 95 | - | 13 | - | 20 |
| | % removal | 85 | - | 85 | - | - | 95 | - | 93 |
| TSS | mg/L | 20 | 30 | 30 | 45 | - | 6 | - | 5 |
| | lbs/day | 42 | 63 | 65 | 95 | - | 8 | - | 8 |
| | % removal | 85 | - | 85 | - | - | 96 | - | 93 |
| Fecal Coliform | cfu/100 mL | 20 | 40 | 20 | 40 | 4 * | - | 140 * | - |
| TRC | mg/L | - | 0.02 | - | - | 0.5 | - | 1 | - |
| pH | S.U. | not outside 6.5-8.5 | | not outside 6.0-9.0 | | 6.7-7.6 | - | 7.8-7.9 | - |
| Flow | MGD | 0.25 | - | 0.25 | - | 0.151 | - | 0.187 | - |
| PLANT 2 | | | | | | | | | |
| BOD5 | mg/L | 20 | 30 | 30 | 45 | - | 34 | - | 43 J |
| | lbs/day | 75 | 115 | 115 | 170 | - | 65 | - | 67 |
| | % removal | 85 | - | 85 | - | - | 82 | - | 85 |
| TSS | mg/L | 20 | 30 | 30 | 45 | - | 36 | - | 38 |
| | lbs/day | 75 | 115 | 115 | 170 | - | 69 | - | 59 |
| | % removal | 85 | - | 85 | - | - | 62 | - | 84 |
| Fecal Coliform | cfu/100 mL | 20 | 40 | 20 | 40 | 2600 * | - | 256 * | - |
| TRC | mg/L | - | 0.02 | - | - | 0.1 | - | 0.1 | - |
| pH | S.U. | not outside 6.5-8.5 | | not outside 6.0-9.0 | | 7.1-7.4 | - | 7.3-7.4 | - |
| Flow | MGD | 0.45 | - | 0.45 | - | 0.230 | - | 0.187 | - |

* = geometric mean.

J = estimated value.

U = analyte not detected. The value given is the sample detection limit.

Shaded area denotes a permit violation.

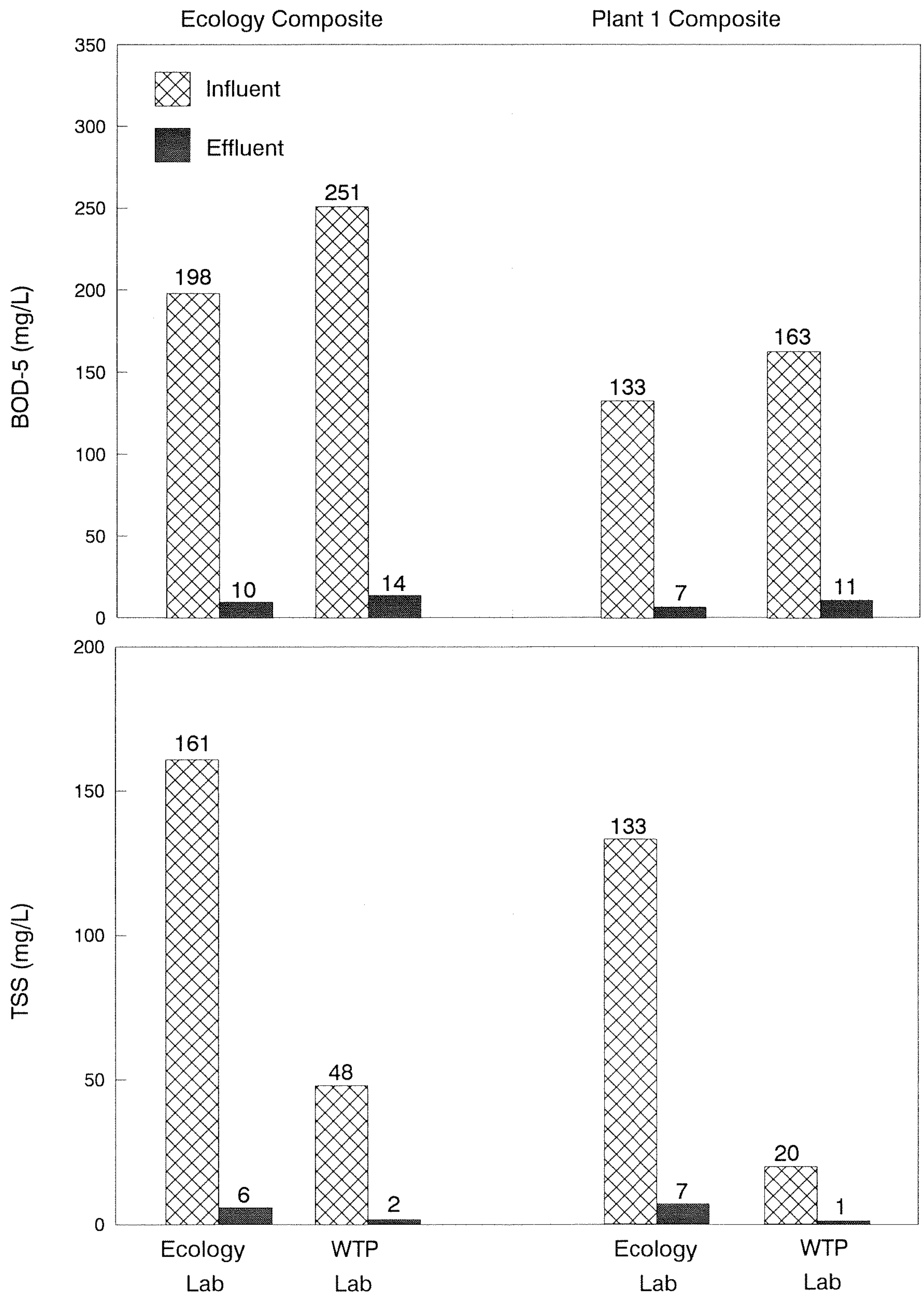



Figure 2. Comparison of BOD-5 and TSS sample splits for Plant 1 (August 29, 1990).

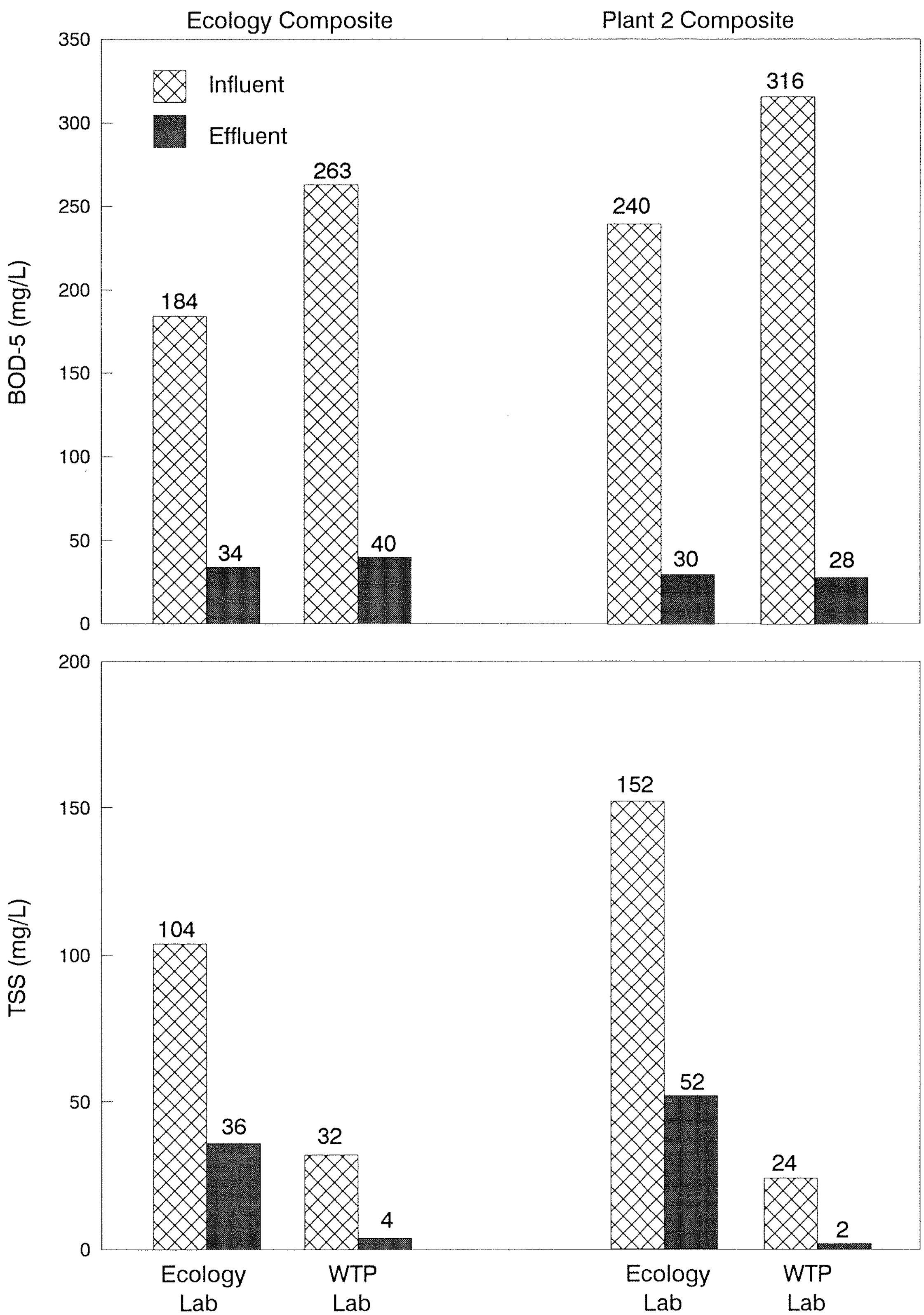



Figure 3. Comparison of BOD-5 and TSS sample splits for Plant 2 (August 29, 1990).

The chlorination system at both plants is continuous feed but not flow weighted. Effluent during peak flows does not appear to receive adequate chlorination. However, TRC at both plants violated permit limits in August, which suggests some other factor may be involved in sporadic chlorination.

<u>Lake Surveys</u>

A complete set of water quality results for West Medical Lake can be found in Appendix B. Table 5 provides summary statistics for water quality data collected during this study. Statistics are from pooled data, including all stations and sampling events. Results indicate that West Medical Lake is extremely enriched. Concentrations of TP ranged from 2.0 to 2.8 mg/L and TN ranged from 1.4 to 2.1 mg/L. The total nitrogen to total phosphorus ratios (N:P) ranged from 0.6 to 1.0. Waterbodies are generally considered to be nitrogen-limited when the N:P ratio is less than 7:1 and phosphorus-limited when the N:P ratio exceeds 17:1 (Forsberg, 1980). In most cases, phosphorus is the most limiting nutrient for algal growth in freshwater lakes (OECD, 1982), but nitrogen may also be limiting, particularly in highly enriched lakes (Welch, 1980). In West Medical Lake, nitrogen would appear to be most limiting. However, both nutrients were available in such excess that some other controlling factor (such as insufficient light or minerals) could actually be limiting algal growth.

Table 6 provides a comparison of 1990 West Medical Lake data to a trophic classification scheme found in OECD (1982). The boundaries between the various trophic classifications should not be rigidly interpreted. Boundary values vary between geographic regions and with beneficial uses of lake waters. However, these trophic status guidelines are generally accepted by most investigators and provide a useful comparison for West Medical Lake.

Notice that the West Medical Lake data exceed the eutrophic thresholds by some margin, and for TP exceed hypereutrophic status. Since no natural surface inflow or outflow is present to flush the system, the lake has been a sink for incoming nutrients from the WTPs over the past 40 to 50 years. Other water quality parameters confirm this highly eutrophic state. Hypolimnetic anoxia occurred during summer months and elevated pH indicated relatively high productivity (Appendix B).

Fecal coliform samples taken at various shoreline areas around the lake (Figure 1) were below detection limits, with the exception of the site in the vicinity of the Plant 2 outfall (Site C). At this site, samples were collected approximately 30 feet from the bank discharge. Results were 13,000 cfu/100 mL on August 28 and 930 cfu/100 mL on October 30 (Appendix B). Chapter 173-201-045 of the WAC states that fecal coliform organisms shall not exceed a geometric mean value of 50 cfu/100 mL in lakes, with not more than 10 percent of samples exceeding 100 cfu/100 mL. In West Medical Lake, high levels of bacteria in the embayment near the Plant 2 outfall are alarming, and could pose a health risk to lake users.

Temperature and dissolved oxygen profiles are provided in Figure 4. Little or no thermal stratification was found during the surveys. Dissolved oxygen profiles did show stratification

Table 5. Summary statistics for water quality determinations on West Medical Lake. Statistics include all stations and sampling events.

| Parameter | Units | N | Range | Mean | | Standard Dev. |
|---|---|---|---|---|---|---|
| LAKE STATIONS | | | | | | |
| Temperature | °C | 53 | 9.0–21.9 | 15.2 | | 5.1 |
| pH | Std Units | 53 | 8.6–9.0 | 9.0 | * | – |
| Dissolved Oxygen | mg/L | 53 | 0.1–13.8 | 8.0 | | 4.4 |
| Dissolved Oxygen | % Saturation | 53 | 1–120 | 77 | | 37 |
| Conductivity | $\mu$mhos/cm | 53 | 756–874 | 814 | | 31 |
| Secchi Disk Depth | meters | 6 | 1.8–4.5 | 2.4 | | 1.0 |
| Alkalinity | mg CaCO3/L | 20 | 320–342 | 331 | | 7 |
| Fecal coliform | CFU/100 mL | 9 | 1–13,000 | 7 | ** | – |
| Total Organic Carbon | mg/L | 20 | 17.5–46.4 | 29.9 | | 6.5 |
| Total P | mg/L | 22 | 1.97–2.76 | 2.35 | | 0.23 |
| Soluble Reactive P | mg/L | 20 | 1.60–2.40 | 2.07 | | 0.19 |
| Total N | mg/L | 22 | 1.38–2.09 | 1.68 | | 0.18 |
| Ammonia N | mg/L | 20 | 0.16–0.99 | 0.35 | | 0.24 |
| Nitrate + Nitrite N | mg/L | 20 | 0.01–0.04 | 0.023 | | 0.015 |
| Total N:P | unitless wt/wt | 22 | 0.55–1.04 | 0.71 | | 0.09 |
| Active Chlorophyll a | $\mu$g/L | 12 | 3.1–41.1 | 22.6 | | 13.7 |
| Phytoplankton biovolume | $mm^3/L$ | 2 | 0.67–0.89 | 0.79 | | 0.14 |

* median value

** geometric mean

Table 6. Trophic status boundaries as suggested by OECD (1982).

| | Mean Annual Values | | | | W. Medical Lake |
|---|---|---|---|---|---|
| Parameter | Oligotrophic | Mesotrophic | Eutrophic | Hypereutrophic | (study mean) |
| TP (mg/L) | 0.008 | 0.027 | 0.084 | 0.75-1.20 | 2.35 |
| TN (mg/L) | 0.661 | 0.753 | 1.875 | - | 1.68 |
| Chl. a (mg/L) | 0.002 | 0.005 | 0.014 | 0.10-0.15 | 0.02 |

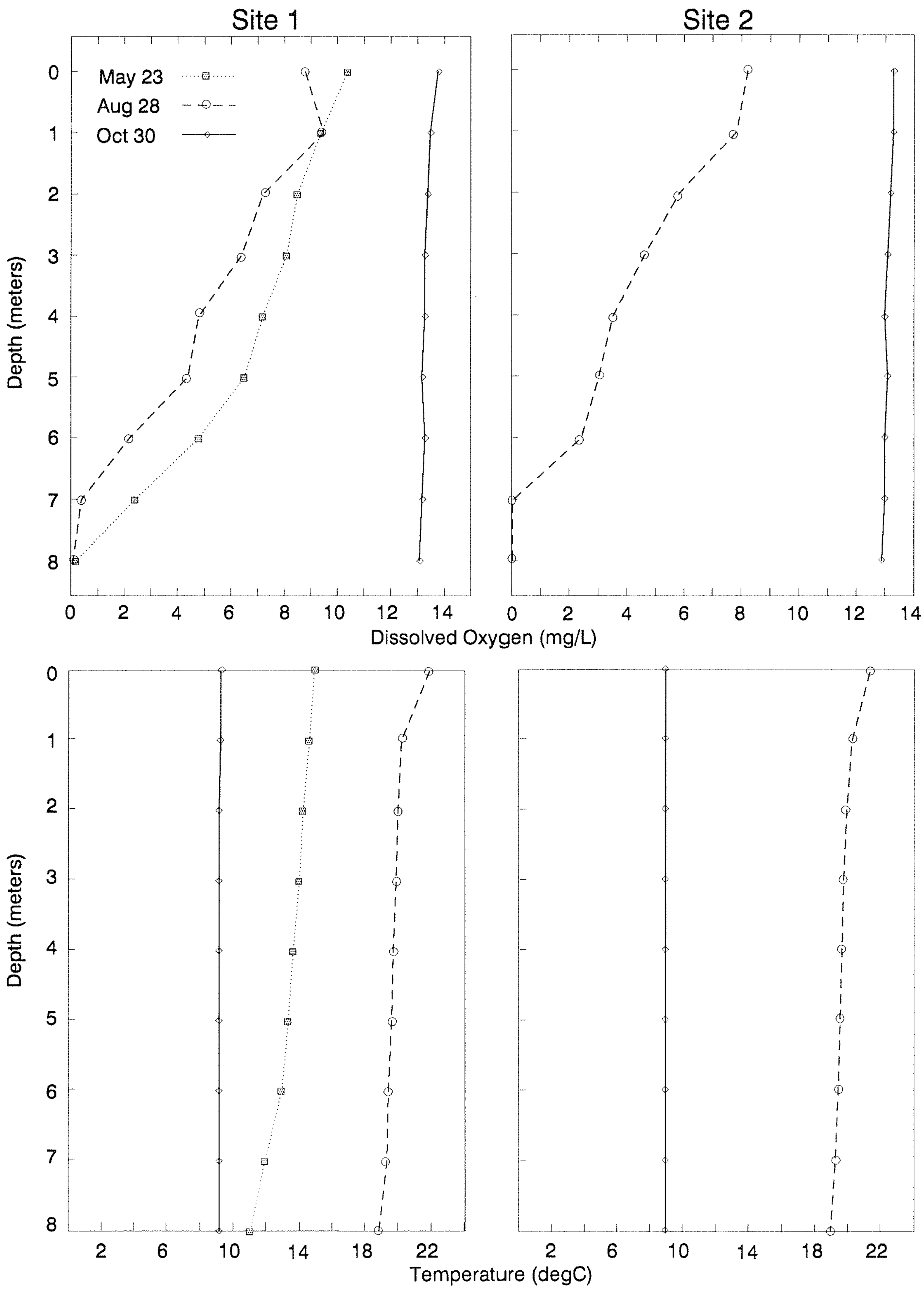



Figure 4. Temperature and dissolved oxygen profiles for West Medical Lake.

and hypolimnetic anoxia during May and August. By October 30, the lake was mixed and oxygen levels were above saturation. The lake had a dense algae bloom at this time, and algal productivity probably contributed to the high oxygen levels recorded.

Lake nutrient data were pooled into two groups, surface to 5 meters and 7 meters to bottom, to assess nutrient stratification (Figures 5 and 6). The example notched box plot in Figure 5 shows how the range, median, and skewness of the data can be determined. The notches radiating out from the median (middle value) of the data set correspond to 95 percent confidence intervals about the median. Notches which extend beyond the 25th or 75th percentiles of the data set can cause the box to fold back on itself. In the example, the notches of two adjacent boxes do not overlap, indicating that the medians are considered significantly different. The width of the box plot is proportional to the square root of the number of observations in the data set. On August 28, TP and SRP concentrations were significantly greater in deeper samples (Figure 5). Phosphorus concentrations collected on October 30 were well mixed through the water column and about equal to deeper samples collected in August.

West Medical Lake nitrogen concentrations are summarized in Figure 6. Concentrations of TN and ammonia were highest in deeper samples on August 28 and well mixed by October 30. Nitrate+nitrite nitrogen was mixed during both surveys, but considerably higher on October 30. Concentrations of total ammonia exceeded chronic toxicity thresholds at ambient temperature and pH in all (20) lake samples collected. Acute toxicity levels for total ammonia were not exceeded.

The criteria for chronic and acute toxicity of total ammonia were calculated by dividing the unionized criteria by the fraction of unionized ammonia present (EPA, 1986). At the temperature and pH in West Medical Lake, the chronic and acute criteria for total ammonia averaged 140 and 880 $\mu$g N/L, respectively. The tenth percentile of chronic and acute criteria (i.e., the criterion values that were more restrictive than 90% of the observed temperature and pH conditions), were 100 and 680 $\mu$g N/L. The actual concentrations of total ammonia in the lake ranged from 160 to 990 $\mu$g N/L, and were typically about 2.5 times the chronic criterion. The WTP effluents contribute most of the nitrogen load to the lake, almost entirely in the form of ammonia. Later sections of this report describe the nitrogen budget and predict possible improvements in water column ammonia.

Summer and fall zooplankton and phytoplankton data are presented in Figure 7 and Appendices C and D. In August, the zooplankton community was dominated by cladocerans, with *Ceriodaphnia lacustris* and *Daphnia pulicaria* most prevalent. Community structure shifted dramatically by October, when rotifers dominated and cladoceran numbers decreased. The rotifer *Keratella quadrata* was most prevalent at this time. Zooplankton communities are cyclic and seasonal variations like this are normal. Zooplankton densities were relatively high in West Medical Lake but species diversity was very low, which is common in eutrophic lakes.

The phytoplankton community was dominated by blue-green algae in August, predominately *Aphanizomenon flos-aquae* and *Microcystis aeruginosa*, both of which are potential toxin

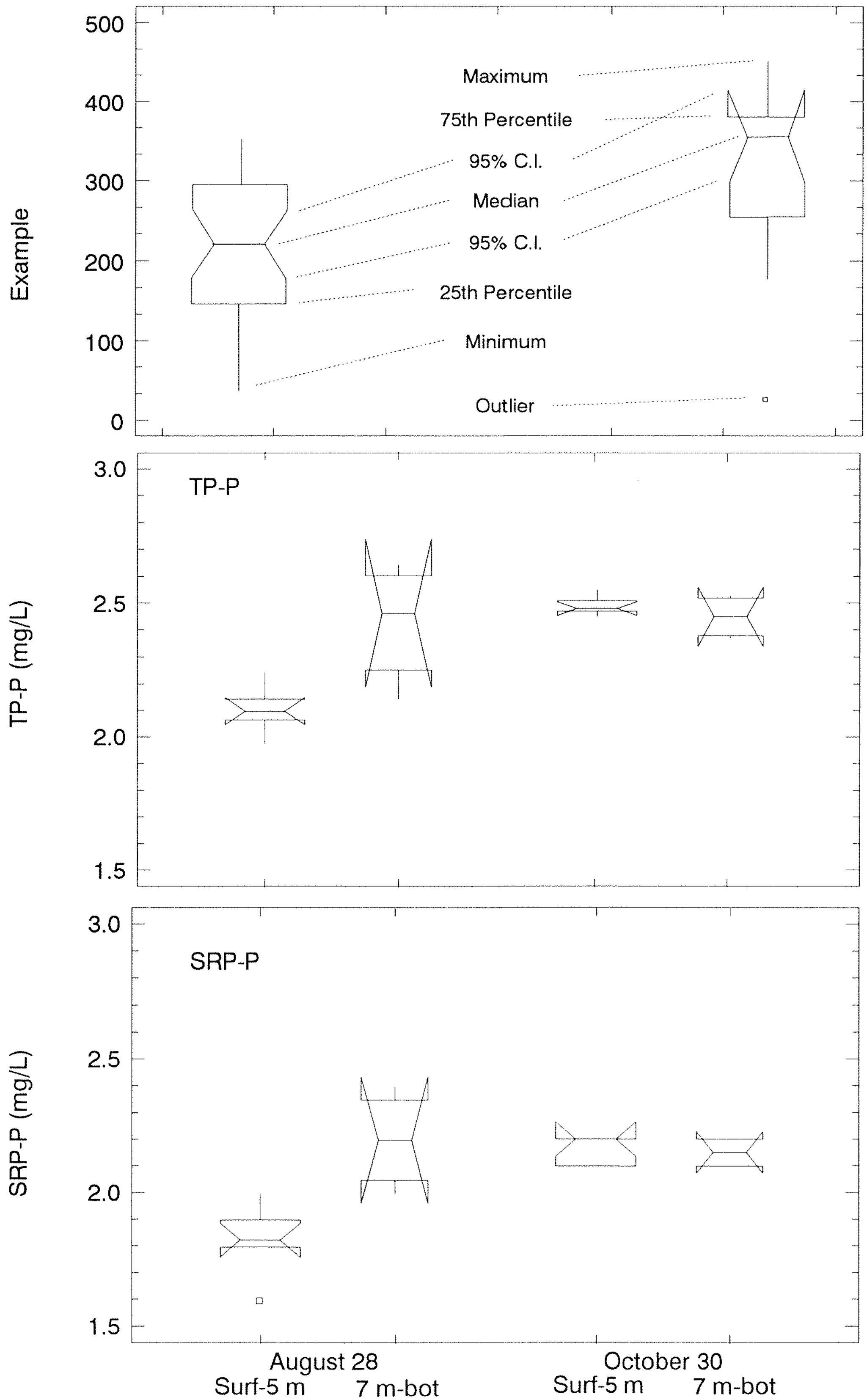



Figure 5. Comparison of phosphorus concentrations by depth in West Medical Lake 1990.

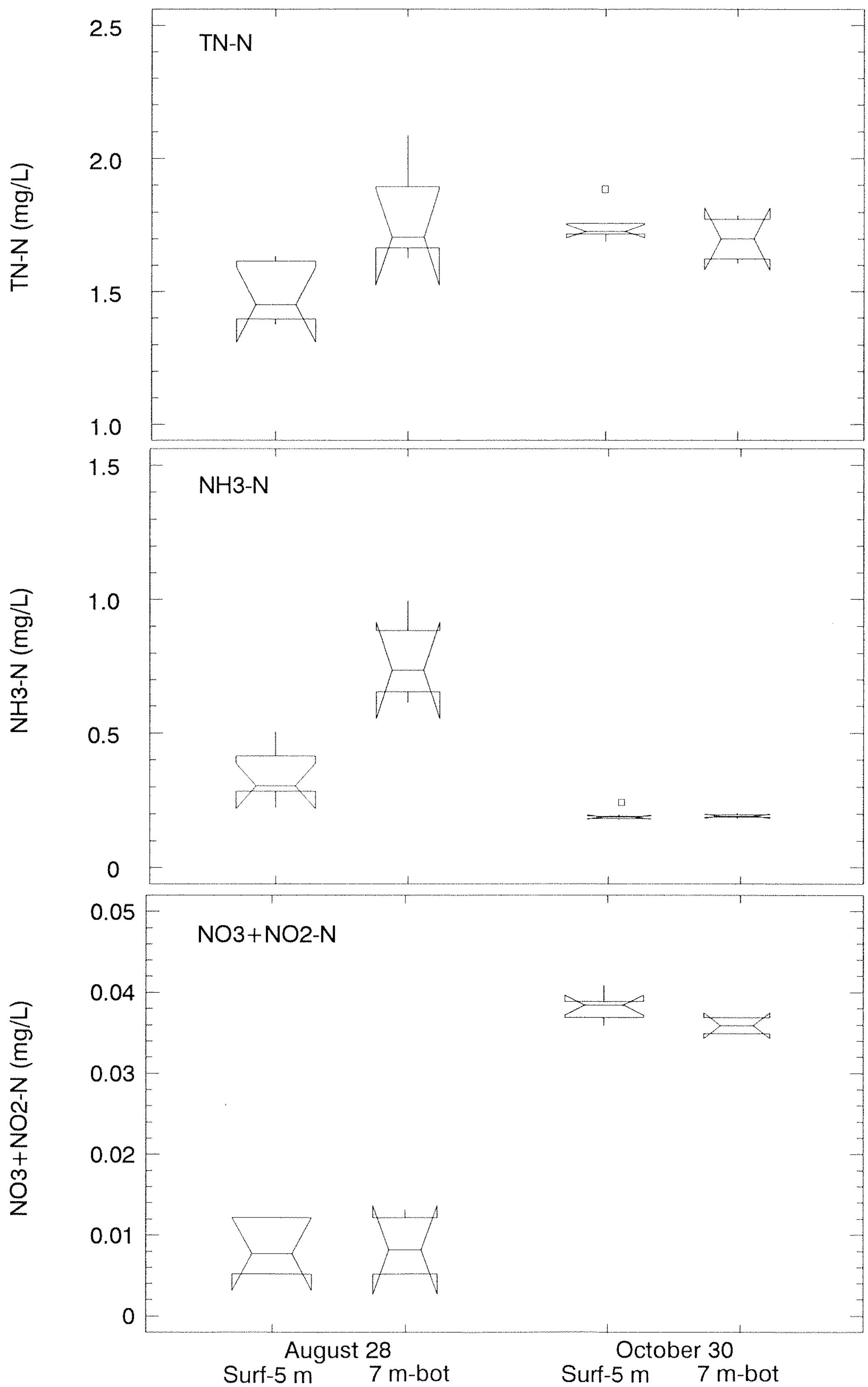
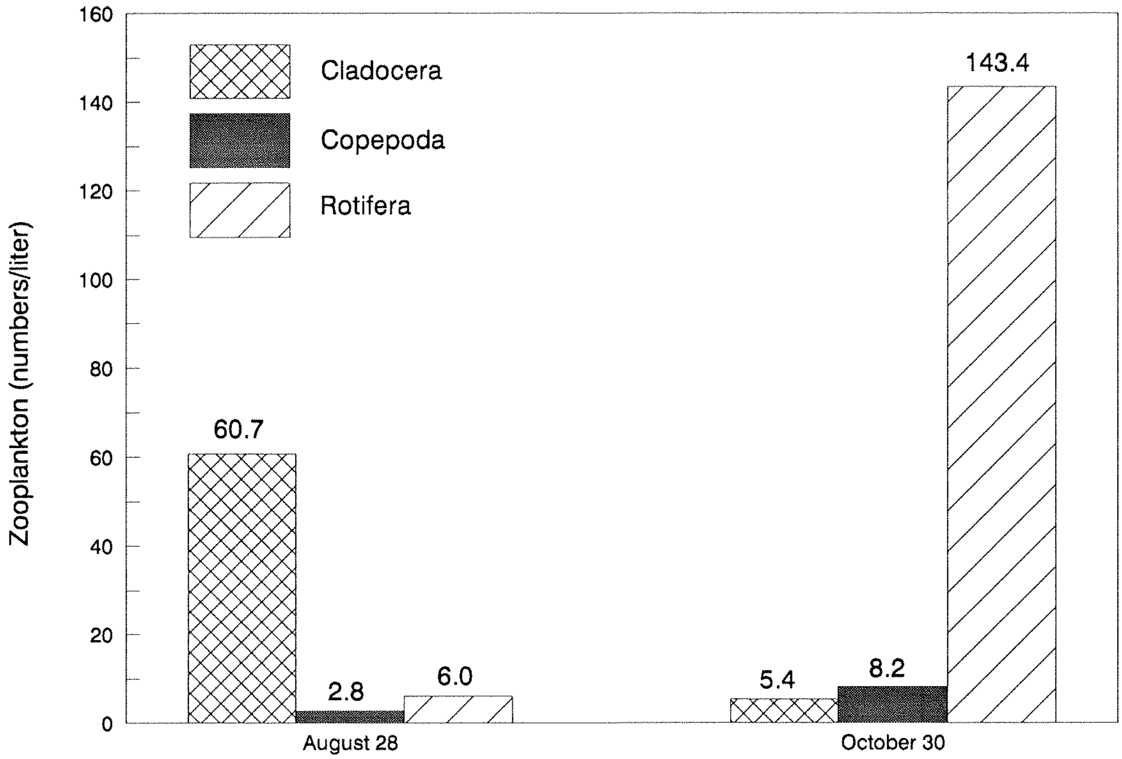



Figure 6. Comparison of nitrogen concentrations by depth in West Medical Lake 1990.



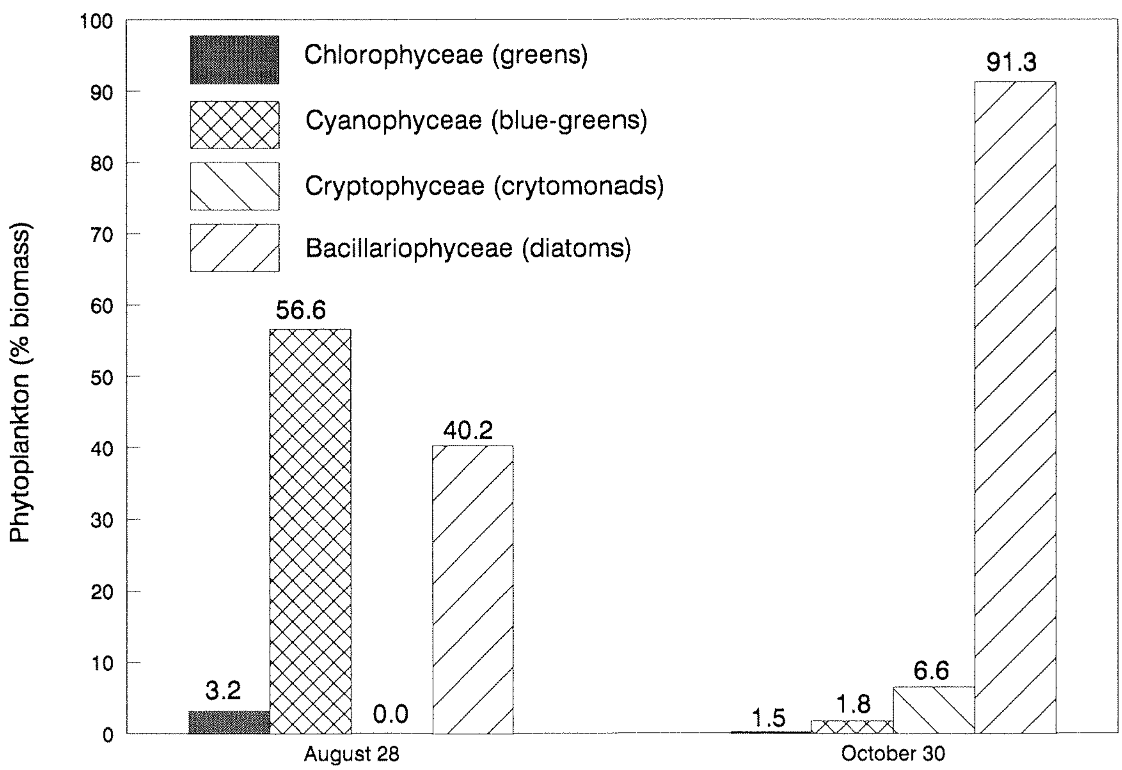




Figure 7. Summary of zooplankton and phytoplankton samples collected at West Medical Lake, 1990.

producers. Diatoms were also very prevalent in August. Diatoms comprised 91.3 percent of the phytoplankton community by biomass on October 30. Blue-greens decreased from 56.6 percent in August to 1.8 percent by October. Like zooplankton, the phytoplankton community was dominated by a few prevalent genera.

## Nutrient Budgets

An annual water budget was developed for the period January through December, 1990 (Table 7). Effluent wastewater accounted for approximately 51 percent of total inflows and precipitation made up the remainder. Outflows included irrigation (13%), evaporation (71%), and groundwater losses (15%). Lake storage change was calculated using annual lake stage data. An average net loss in lake storage was determined for 1990. Balancing the water budget, using groundwater as the unknown, indicated a net outflow through groundwater. The large standard error associated with this estimate could indicate a net gain or loss through groundwater. The hydraulic overflow (outflow per unit surface area) was estimated from net outflow (irrigation and groundwater) corrected for storage change to be $0.23 \pm 0.25$ m/year. The corresponding hydraulic residence time in the lake is approximately 29 years.

Table 8 provides annual phosphorus and nitrogen budgets for West Medical in 1990. The combined loads from both WTPs accounted for approximately 89 and 63 percent of the total phosphorus and nitrogen external loads, respectively. Nonpoint source and atmospheric loading, estimated using literature values, made up the remainder. The only outflows for lake nutrients were through irrigation and groundwater losses. The differences between estimated external loads and outflow loads corrected for storage change were assumed to represent net sedimentation within the lake.

The effect of internal sediment recycling of nutrients was estimated using equations (2) and (3). The net settling velocity $fv_s$ was found to be about 1.3 m/year for total P and 3.6 m/year for total N, which is considerably lower than reported values in the absence of sediment feedback. Since West Medical Lake does have significant sediment recycling the above values seem appropriate. Approximately 11 percent of sedimented total P and 36 percent of total N is estimated to be buried in deep sediments, with the remainder recycled in the water column.

The large internal recycling of nutrient loads in West Medical Lake was not surprising for several reasons. First, having no natural surface water inflow or outflow to flush the system, the lake has been a sink for incoming nutrients from the WTPs over the last 50 years. Second, the lakes shallow depth (mean depth of 6.7 meters) probably facilitates regular mixing and recycling of sediment nutrients back into the water column. And third, the release of phosphorus occurs from the sediments during periods of hypolimnetic anoxia and high pH.

It is generally accepted that a mesotrophic condition may adequately support important water uses such as recreation and fisheries production. The most rigorous attempt to provide boundary values for various water quality parameters to describe trophic status was presented by OECD (1982). The OECD scheme is based on a probabilistic evaluation of extensive limnological data

Table 7. West Medical Lake annual water budget, January through December, 1990.

| WATER BUDGET COMPONENT | ANNUAL TOTAL ($m^3$/year) Mean | ± | Std Err |
|---|---|---|---|
| OUTFLOWS | | | |
| Irrigation (1) | 131,300 | ± | 49,200 |
| Evaporation (2) | 696,700 | ± | 195,000 |
| Groundwater (3) | 200,800 | ± | 215,700 |
| STORAGE CHANGE (1) | -124,800 | ± | 12,500 |
| INFLOWS | | | |
| Precipitation (2) | 443,400 | ± | 75,300 |
| Plant 1 (Lakeland Village WTP)(4) | 220,200 | ± | 2,700 |
| Plant 2 (E. State Hosp. WTP)(4) | 240,400 | ± | 3,800 |
| Net Hydraulic Overflow "q" (m/year)(5) | 0.23 | ± | 0.25 |

Footnotes:

1) Irrigation and storage change based on water withdrawal and lake stage information obtained from Consolidated Support Services. Negative storage change represents a net decrease in level from 6.20 to 5.74 feet.
2) Evaporation and precipitation based on NOAA climatological data from Spokane WSO airport station. Lake evaporation was estimated from pan data assumming a pan coefficient of 0.6 (Linsley et al., 1975).
3) Groundwater Outflow = inflows - Irrigation - Evaporation - Storage Change. A negative value indicates net groundwater inflow.
4) Plant 1 and 2 inflows are based on DMR discharge data for 1990.
5) $q_s$ = (Irrigation + Groundwater + Storage Change)/(Lake Surface Area).

Table 8. West Medical Lake annual nutrient budgets, January through December, 1990.

| NUTRIENT MASS LOADING: | (Kg P/year) | | | (Kg N/year) | | |
|---|---|---|---|---|---|---|
| EXTERNAL | | | | | | |
| Plant 1 (1) | 1,150 | ± | 117 | 763 | ± | 182 |
| Plant 2 (1) | 1,657 | ± | 234 | 2,865 | ± | 870 |
| Nonpoint Sources (2) | 320 | ± | 160 | 1,123 | ± | 562 |
| Atmospheric Deposition (3) | 25 | ± | 5 | 979 | ± | 196 |
| TOTAL : | 3,152 | ± | 307 | 5,730 | ± | 1,070 |
| OUTFLOWS | | | | | | |
| Irrigation (4) | 390 | ± | 116 | 221 | ± | 86 |
| Groundwater (5) | 354 | ± | 1,395 | 253 | ± | 997 |
| TOTAL: | 744 | ± | 1,400 | 474 | ± | 1,001 |
| STORAGE CHANGE (6) | -293 | ± | 41 | -210 | ± | 31 |
| NET SEDIMENTATION (7) | 2,701 | ± | 1,434 | 5,466 | ± | 1,465 |
| NUTRIENT AREAL LOADING (mg/m²/year | (mg P /m²-year) | | | (mg N /m²-year) | | |
| EXTERNAL | | | | | | |
| Plant 1 | 1,292 | ± | 146 | 857 | ± | 209 |
| Plant 2 | 1,862 | ± | 279 | 3,219 | ± | 991 |
| Nonpoint Sources | 360 | ± | 181 | 1,262 | ± | 635 |
| Atmospheric Deposition | 28 | ± | 6 | 1,100 | ± | 227 |
| TOTAL EXTERNAL LOAD "L": | 3,542 | ± | 363 | 6,438 | ± | 1,216 |
| ACTUAL SETTLING VELOCITY "$fv_s$" (m/y): $fv_s = (L/P) - q_s$ | 1.3 | ± | 0.3 | 3.6 | ± | 0.9 |
| FRACTION OF EXTERNAL NUTRIENT LOAD BURIED IN DEEP SEDIMENT (8): Lorenzen's $f = fv_s/12$ | 11% | ± | 4% | 36% | ± | 14% |

Footnotes:

1) Estimated by averaging daily loads from effluent composites collected on 8/29, 9/8, 9/22, 10/4, and 10/31/91 and then expanding for the entire year.

2) Estimated using non-point export rates measured for 3 Washington drainages (68 Kg P/Km²/yr and 239 Kg N/Km²/yr) (EPA 1974). Coefficient of variation assumed equal to 50%.

3) Estimated from a total areal P of 28 mg P/m²/yr and total areal N of 1,100 mg N/m²/yr (Patmont et al., 1989). Coefficient of variation assummed to equal 20%.

4) Estimated as outflow irrigation discharge from water budget multiplied by study mean lake TP (2.35 ± 0.23 mg P/L) and TN (1.68 ± 0.18 mg N/L).

5) Estimated as outflow groundwater discharge from water budget multiplied by mean lake TP (2.35 ± 0.23 mg P/L) and TN (1.68 ± 0.18 mg N/L).

6) Estimated as storage volume increase multiplied by whole lake mean TP (2.35 ± 0.23 mg P/L) and TN (1.68 ± 0.18 mg N/L).

7) Estimated as External Loading - outflow - storage increase.

8) Lorenzen's f estimated as actual settling velocity "$fv_s$" divided by typical $v_s$ in lakes with insignificant internal feedback (i.e., assuming $v_s$ = 12 m/y)

collected from lakes and reservoirs throughout the northern temperate zone. The probability of attaining various trophic levels in West Medical Lake based on predicted whole-lake TP concentrations and trophic state probabilities reported by OECD (1982).

Lake Management Alternatives for Eutrophication Control

A steady-state mass balance model (equation 1) was used to predict whole-lake TP and TN concentrations, and trophic status under various loading scenarios (Table 9). This analysis indicated that major TP control for both external and internal loading would be needed to enhance the trophic status of West Medical Lake from hypereutrophic to eutrophic. Reduction of external sources alone would probably not provide any discernable improvement in water quality. The severity of algal blooms would be reduced if eutrophic conditions are attained, although blooms would still be common. Other improvements might include: higher oxygen content at all depths in the lake, increased water transparency, and greater biological diversity.

Reduction of internal phosphorus recycling by sediment inactivation (see below) was estimated by assuming that the fraction of nutrient burial to deep sediments could be increased to about 60 percent. This amount of recycling represents a midpoint between the existing condition and insignificant recycling. A similar value of nutrient burial was reported by Lorenzen *et al.*, (1976) for Lake Washington during a period of eutrophication from WTP inputs.

Three different levels of advanced waste treatment were examined for removal of effluent P. The range of effluent TP from 0.5 to 2.0 mg/L represents a typical range for performance of various advanced treatment processes (Metcalf and Eddy, 1991).

Loading scenarios 5 and 6 in Table 9 suggest that an improvement from hypereutrophic to eutrophic conditions is possible by reducing in-lake TP to less than 200 $\mu$g P/L. Such an improvement is only possible if advanced treatment is used to reduce effluent P and sediment inactivation is implemented (e.g., through in-lake alum treatments). Scenario 6 provides the best chance of improvement by limiting effluent flows to existing (1989-90) average annual rates instead of allowing expansion to currently permitted average flows. Trophic status improvement requires effluent total P to be limited to 0.5 mg P/L if currently permitted flows are allowed or 1.0 mg P/L if permissible flows are reduced to existing annual averages.

The response time required for the lake to reach 90 percent equilibrium towards the steady state concentrations in Table 9 was predicted using equation 4. For scenarios that do not involve sediment P inactivation (scenarios 3 and 4) the response time is at least 10 years before improvements are attained. A faster response time of about 2 years is predicted with sediment inactivation because of increased sedimentation and reduced sediment feedback (scenarios 5 and 6).

The use of phosphorus limitation to control eutrophication in lakes is common practice. Phosphorus is considered a more manageable nutrient than nitrogen for several reasons, including: existence of proven technology for removal of phosphorus from wastewaters; available

Table 9. Summary of in-lake nutrient concentrations for various loading scenarios.

| Loading Scenario | Lake Total P ($\mu$g P/L) | Lake Total N ($\mu$g N/L) | Total N:P Ratio (wt:wt) | Trophic State Probability (OECD, 1982) Mesotrophic or better | Eutrophic | Hypereutrophic or worse |
|---|---|---|---|---|---|---|
| 1) EXISTING CONDITION (1990) | 2,350 | 1,680 | 0.7 | <1% | <2% | 98% |
| 2) EXISTING WTP LOADS WITH IN-LAKE SEDIMENT P INACTIVATION ONLY (e.g. Alum treatment) | 480 | 1,680 | 3.5 | <1% | 6% | 94% |
| 3) PERMITTED WTP FLOWS WITH ADVANCED WASTE TREATMENT, NO IN-LAKE CONTROLS (Plant 1 = 0.25 MGD; Plant 2 = 0.45 mgd) | | | | | | |
| 2.0 mg/L effluent TP | 1,700 | 2,900 | 1.7 | <1% | <2% | 98% |
| 1.0 mg/L effluent TP | 960 | 2,900 | 3.0 | <1% | <2% | 98% |
| 0.5 mg/L effluent TP | 610 | 2,900 | 4.8 | <1% | 3% | 97% |
| 4) EXISTING WTP FLOWS (1989-90 average) WITH ADVANCED WASTE TREATMENT, NO IN-LAKE CONTROLS (Plant 1 = 0.15 mgd; Plant 2 = 0.18 mgd) | | | | | | |
| 2.0 mg/L effluent TP | 920 | 1,680 | 1.8 | <1% | <2% | 98% |
| 1.0 mg/L effluent TP | 590 | 1,680 | 2.8 | <1% | 4% | 96% |
| 0.5 mg/L effluent TP | 420 | 1,680 | 4.0 | <1% | 8% | 92% |
| 5) SAME AS 3) PLUS IN-LAKE SEDIMENT P INACTIVATION | | | | | | |
| 2.0 mg/L effluent TP | 340 | 2,900 | 9 | <1% | 13% | 87% |
| 1.0 mg/L effluent TP | 200 | 2,900 | 15 | 1% | 34% | 65% |
| 0.5 mg/L effluent TP | 125 | 2,900 | 23 | 6% | 57% | 37% |
| 6) SAME AS 4) PLUS IN-LAKE SEDIMENT P INACTIVATION | | | | | | |
| 2.0 mg/L effluent TP | 190 | 1,680 | 9 | 1% | 37% | 62% |
| 1.0 mg/L effluent TP | 120 | 1,680 | 14 | 7% | 58% | 35% |
| 0.5 mg/L effluent TP | 87 | 1,680 | 19 | 16% | 65% | 19% |

techniques for controlling internal phosphorus cycles; and phosphorus limitation seems to be the most effective means to control the growth of some nitrogen-fixing blue-green algae (Welch, 1980; Cooke *et al.*, 1986). Scenarios 5 and 6 in Table 9 indicate that P concentrations could be reduced to the point where P is more limiting than N if external and internal loading controls are implemented.

Table 10 provides a summary of current technologies available to reduce nutrient concentrations in lakes (Cooke *et al.*, 1986). While it is beyond the scope of this report to examine the feasibility of all potential restoration measures, several seem most appropriate for West Medical Lake. Advanced treatment of point sources using iron or aluminum salts to precipitate and remove phosphorus is common practice. Advanced treatment such as this would probably be preferred over diversion of point sources given that approximately 51 percent of the flows into the lake come from the WTPs. Removing the point sources would dramatically impact current lake levels.

The present use of aerators could be considered an internal loading control provided that anaerobic conditions are prevented. However, development of high pH conditions allows significant internal P loading under aerobic conditions. Aeration alone probably is not sufficient to reduce internal loading since high pH conditions occur and internal feedback is significant even with current aeration practices. Aeration should be continued even if other in-lake controls are implemented since maintaining aerobic conditions improves fish habitat and probably helps to control internal P loading.

In-lake phosphorus precipitation and inactivation using aluminum salts, usually aluminum sulfate (alum), is commonly used in restoration projects to control internal phosphorus cycling. When alum is added to lake water, phosphorus is removed by an $AlPO_4$ precipitate, by sorption of phosphorus on the surface of $Al(OH)_3$ floc, and by entrapment and sedimentation of phosphorus-containing particulate matter in the $Al(OH)_3$ floc. Aluminum is the element usually chosen for phosphorus precipitation and inactivation applications because the resultant complexes and polymers are inert to redox changes such as occur in an anoxic hypolimnion, and therefore, release of phosphorus from the sediments would be minimal.

Following the whole lake alum application of Medical Lake, Washington, in 1977, TP and SRP concentrations decreased by 83 and 94 percent, respectively (Gasperino and Soltero, 1980). Water quality as a result improved dramatically. Medical Lake is located adjacent to West Medical Lake and has similar limnological characteristics, except it has no point source discharges. It seems reasonable given the similarities of the two systems that the success of phosphorus inactivation in Medical Lake could be accomplished in West Medical Lake with similar treatment.

Presently, the major use of West Medical Lake by the general public is a recreational fishery. The major reason that planted trout grow so rapidly is due to the lakes current high productivity. If the nutrient controls described above were successful in bringing the lake into a eutrophic range, then the lakes ability to support present stocking levels may decrease. However, a

Table 10. Summary of physical and chemical methods available to reduce nutrient concentrations in lakes (Cooke et al., 1986).

| |
|---|
| External Loading Controls |
| 1) Advanced treatment of point sources (nutrient removal) |
| 2) Diversion of point sources |
| 3) Non-point source controls |
| |
| Internal Loading Controls |
| 1) Dilution and flushing |
| 2) Phosphorus precipitation and inactivation (e.g. Alum application) |
| 3) Sediment oxidation (e.g. nitrate addition) |
| 4) Sediment removal |
| 5) Hypolimnetic withdrawal |
| 6) Hypolimnetic aeration |
| 7) Biological controls (e.g. food web manipulations) |

Shaded areas denote most applicable techniques for West Medical Lake.

eutrophic status would still support a productive fishery and may protect the fishery in the long-term. Also, enhanced water quality could potentially increase usable fish habitat and allow other beneficial uses, such as swimming and recreation to be developed around the lake.

Ammonia Concentration Reduction

The existing concentrations of total ammonia in West Medical Lake consistently exceed the chronic criterion for toxicity. The chronic and acute toxicity criteria were set by EPA (EPA, 1986) at the threshold of actual toxic effects. Therefore, violation of the criterion is not expected to result in immediate widespread toxicity. However, criteria violation is a warning that toxicity to the most sensitive species may begin to occur, especially if concentrations greatly exceed the criterion. Given that fish kills do not appear to be a chronic problem in West Medical Lake, the concentration of ammonia currently may be lower than the actual toxic level for fish in the lake even though the chronic criterion is exceeded. Nevertheless, the potential for actual toxic effects by ammonia is indicated and the criterion value is generally interpreted as the water quality standard. Ecology has adopted the federal criteria for ammonia as the State water quality standard (Chapter 173-201 WAC).

In-lake ammonia predictions were made for various WTP loading scenarios (Table 11) by first calculating the TN mass balance in the same way as for TP. Next, the observed ratio of ammonia to TN in the lake (19% $\pm$ 3% of in-lake TN was ammonia N during 1990) was applied to predicted TN to estimate the ammonia concentration. The predicted in-lake ammonia concentration was then compared with chronic toxicity criteria (Table 11). This analysis suggests that effluent TN concentrations would need to be reduced below 1.0 mg N/L to achieve in-lake ammonia concentration reductions to the chronic criterion. If no reductions in effluent ammonia are implemented and WTP flows increase to the permitted flows, then in-lake ammonia concentrations will probably increase to about four times the chronic criterion (Table 11).

The predictions in Table 11 for loading scenarios 3 and 4 may overestimate in-lake ammonia since the fraction of the TN load that is ammonia would probably decrease with decreasing WTP effluent TN. Therefore, the ammonia to TN ratio in the lake may also decrease, which may result in further reductions below the chronic criterion. Also, if phosphorus loading reductions are successful at reducing primary productivity, the pH may decrease, which will increase the ammonia criterion. For example, if maximum pH decreases from 9.0 to 8.3 as a result of TP loading reductions, then the chronic ammonia criterion would be met at existing TN loads. More certain predictions of ammonia concentrations and criteria probably are not possible. However, it seems possible that chronic ammonia criteria could be met through a combination of phosphorus and nitrogen controls.

A phased approach of phosphorus and nitrogen loading controls may be appropriate. First, phosphorus loading controls and/or in-lake controls could be implemented and lake response monitored. Next, if TP reductions result in significantly lower pH, the need for TN controls could be reassessed. If pH levels still are high enough (and ammonia criteria are low

Table 11. Summary of in-lake total nitrogen and ammonia concentrations for various loading scenarios. All ammonia concentration values and criteria are in units of total ammonia N, where total ammonia criteria are determined by dividing the unionized ammonia criteria by the fraction of unionized ammonia.

| Loading Scenario | Lake Total N ($\mu$g N/L) | Lake Ammonia N ($\mu$g N/L) | Average Chronic Ammonia N Criterion ($\mu$g N/L) | 10 %tile Chronic Ammonia N Criterion ($\mu$g N/L) |
|---|---|---|---|---|
| 1) EXISTING CONDITION (1990 | 1,680 | 350 | 140 | 100 |
| 2) PERMITTED WTP FLOWS WITH EXIXTING (1990) EFFLUENT AMMONIA CONCENTRATIONS (Plant 1 = 0.25 MGD; Plant 2 = 0.45 mgd; Effluent TN = 8.0 mg N/L) | | | | |
| 8.0 mg/L effluent TN | 2,890 | 563 | 140 | 100 |
| 3) PERMITTED WTP FLOWS WITH ADVANCED WASTE TREATMENT (Plant 1 = 0.25 MGD; Plant 2 = 0.45 mgd) | | | | |
| 4.0 mg/L effluent TN | 1,750 | 341 | 140 | 100 |
| 2.0 mg/L effluent TN | 1,180 | 230 | 140 | 100 |
| 1.0 mg/L effluent TN | 900 | 175 | 140 | 100 |
| 0.5 mg/L effluent TN | 760 | 148 | 140 | 100 |
| 4) EXISTING WTP FLOWS (1989–90 average) WITH ADVANCED WASTE TREATMENT (Plant 1 = 0.15 mgd; Plant 2 = 0.18 mgd) | | | | |
| 4.0 mg/L effluent TN | 1,150 | 224 | 140 | 100 |
| 2.0 mg/L effluent TN | 880 | 171 | 140 | 100 |
| 1.0 mg/L effluent TN | 750 | 146 | 140 | 100 |
| 0.5 mg/L effluent TN | 680 | 132 | 140 | 100 |

enough) to cause ammonia criteria violation after TP reductions are implemented, the ammonia concentration could be reduced through effluent TN loading reductions.

## SUMMARY AND CONCLUSIONS

### Limited Class II Inspection

- Effluent quality was poorer at Plant 2 (Eastern State Hospital WTP), where fecal coliform, TSS, $BOD_5$, TOC, TP, TN, and ammonia concentrations were considerably higher than at Plant 1 (Lakewood Village WTP). Effluent discharge averaged 0.16 MGD at Plant 1 and 0.20 MGD at Plant 2 for the study.

- Sample splits between Ecology's lab and both WTP labs were not very comparable, especially for TSS.

- New NPDES permits were issued for both WTPs, effective October 23, 1990. The new permits were less restrictive for several parameters including $BOD_5$, TSS, total residual chlorine, and pH.

- At Plant 1, effluent composite concentrations for $BOD_5$ and TSS were well below permit limits. Removal for both parameters ranged from 93 to 96 percent.

- Plant 2 was approaching its weekly permit limits for $BOD_5$ and TSS concentrations during both surveys. Removal ranged from 82 to 85 percent for $BOD_5$ and 62 to 84 percent for TSS.

- Exceedance of the fecal coliform permit limit was measured in 5 of 6 effluent samples collected at Plant 2. Plant 1 also violated its fecal coliform limit, but less frequently than Plant 2. Effluent does not appear to receive adequate disinfection during peak flows.

### Lake Surveys

- Results of water quality determinations indicated that West Medical Lake is extremely enriched. Concentrations of TP ranged from 2.0 to 2.8 mg/L and TN ranged from 1.4 to 2.1 mg/L. The N:P ratio ranged from 0.6 to 1.0, which suggests nitrogen may be limiting algal growth. However, both nitrogen and phosphorus were present greatly in excess of concentrations that actually limit algal growth.

- When compared to trophic status boundaries developed by OECD (1982), West Medical Lake data exceeded eutrophic and hypereutrophic threshold values. Hypolimnetic anoxia and elevated pH measured during the surveys support this conclusion.

- Fecal coliform samples collected in the embayment near the Plant 2 outfall were extremely high. Results were 13,000 cfu/100 mL on August 28 and 930 cfu/100 mL on October 30. These levels are alarming and could pose a health risk.

- The phytoplankton community was dominated by blue-green algae, predominately *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* during August. Diatoms dominated in October.

- Chronic toxicity criteria for ammonia were consistently exceeded. Ammonia concentrations in the lake were typically about 2.5 times the chronic criterion value.

**Nutrient Budgets**

- An annual water budget indicated that effluent wastewater accounted for approximately 51 percent of total inflows, with precipitation making up the remainder. Outflows included irrigation (13%), evaporation (71%) and groundwater losses (15%).

- Annual nutrient budgets indicated that the combined loads from both WTPs accounted for approximately 89 and 63 percent of the total phosphorus and nitrogen external loads, respectively.

- Internal recycling of nutrients was found to be significant. The large internal loads were not surprising for several reasons including: the lack of any natural surface water inflow or outflow to flush the system; relatively shallow depth; allowing the lake to mix regularly; and release of phosphorus from sediment during periods of hypolimnetic anoxia and high pH.

**Lake Management Alternatives**

- A steady-state mass balance model used with various loading scenarios indicated that reduction of point source nutrients alone would not provide any discernable improvements in water quality. TP controls for both external and internal loading would be needed to enhance lake trophic status.

- Advanced treatment of point sources, and precipitation and inactivation of internal loading using aluminum sulfate (alum), appear to be the most appropriate techniques for controlling external and internal phosphorus loading. Reductions of permissible effluent flows to current annual averages should also be considered for long-term management of external loads if advanced treatment is considered. The combination of these techniques would probably shift the trophic state from the existing hypereutrophic condition to a eutrophic state. Improvements could be attained within 2 years of implementation of external and internal loading controls.

- Ammonia concentrations are likely to increase to about four times the chronic criterion if WTP effluent concentrations remain the same, and WTP flows increase to the permit maximum. Effluent TN reductions to less than 1.0 mg N/L may reduce in-lake ammonia concentrations to the chronic criterion. Attainment of ammonia criteria may also be enhanced by decreased algal productivity and pH if phosphorus controls are implemented.

## RECOMMENDATIONS

- Both WTP laboratories did not perform well on TSS split sample comparisons. A review of laboratory procedures is in order. Both labs should be working towards lab accreditation if they plan on continuing their own analyses in the future.

- Plant 2 was approaching its permit limit for $BOD_5$ and TSS. A plant upgrade may be needed to accommodate future growth. A more detailed engineering diagnostic study may be warranted to determine if the existing plant could be operated more efficiently.

- Adequate disinfection during peak flows is not occurring at Plant 2, resulting in high bacteria levels reaching the lake. Design of the chlorination system should be subjected to an engineering review and any flaws immediately corrected to provide maximum protection to lake users.

- Current effluent nutrient loading results in a hypereutrophic condition of West Medical Lake. Weekly monitoring for TP, TN and ammonia should be incorporated into the NPDES permit to better assess nutrient loads and impacts.

- Lake water quality would not be expected to improve as a result of point source controls alone, due to internal nutrient cycling. The combined control of both external and internal loading would be the only way to improve water quality.

- If improvement to eutrophic status is considered a desirable goal, then advanced treatment rather than point source diversion seems to be the best alternative for controlling point sources, given that over 51 percent of inflows to the lake are from the WTPs. If wastewater were diverted, current lake levels could dramatically decline. With current advanced treatment technology, possibly combined with reducing sources of P to the WTP, effluent phosphorus concentrations could be reduced to 0.5 to 1.0 mg/L. If permitted flows are reduced to current annual averages, effluent total P of 1.0 mg/L should be sufficient to improve lake quality to eutrophic conditions if internal lake controls are also used.

- Non-phosphate detergents have been used at both facilities since June 1990 (personal communication, Lisa Humphreys, Department of Ecology). Further evaluation of potential sources of phosphorus to WTP influent could be investigated. Improved source reduction could reduce potential costs of achieving lower effluent TP concentrations.

- The recommended technique for controlling internal phosphorus loading in West Medical Lake is chemical precipitation and inactivation using alum combined with aeration. To achieve high removal, several successive alum treatments may be needed. Laboratory testing using West Medical Lake water to determine appropriate application rates would be necessary to determine the feasibility of this plan.

- Eutrophication of West Medical Lake has been accelerated by wastewater discharge over the years. Presently, the lake receives very little recreational use, other than sport fishing. In it's present state, the lake could not consistently support this fishery without the use of the current aeration system in the lake. Continued, unrestricted nutrient loading will only further degrade lake quality in the future, possibly to the point where it becomes intolerable to fish. For that reason, it is recommended that a plan be developed with a long term goal of improving water quality through nutrient loading reductions.

- A phased approach of phosphorus and nitrogen loading controls may be appropriate to achieve ammonia criteria. If TP reductions result in significantly lower pH through reduced algal productivity, the need for effluent TN reductions could be reassessed. If ammonia criteria do not increase after TP reductions are in place, the ammonia concentrations could be reduced through effluent TN reductions.

## REFERENCES


APHA (American Public Health Association, American Water Works Association, and Water Pollution Control Federation), 1989. Standard Methods for the Examination of Water and Wastewater, 17th ed., Washington DC.

Chapra, S.C. and K.H. Reckhow. 1983. Engineering Approaches for Lake Management, Volume 2: Mechanistic Modeling. Butterworth Publishers.

Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth, 1986. Lake and Reservoir Restoration. Butterworth Publishers, Stoneham, MA, 392 pp.

Dion, N.P., G.C. Bortlleson, J.B. McConnell, and L.M. Nelson, 1976. Reconnaissance Data on Lakes in Washington, Volume 7. Water Supply Bulletin 43. Prepared in cooperation with the U.S. Geological Survey.

EPA, 1974. The Relationship of Phosphorus and Nitrogen to the Trophic State of Northeast and North-Central Lakes and Reservoirs. National Eutrophication Survey Working Paper No. 23. U.S. Environmental Protection Agency.

------, 1983. Methods for Chemical Analysis of Water and Wastes. U.S. Environmental Protection Agency. EPA 600/4-79-020, Cincinnati, Ohio.

------, 1986. Quality Criteria for Water, 1986. U.S. Environmental Protection Agency. EPA 440/5-86-001.

Forsberg, C., 1980. "Present Knowledge on Limiting Nutrients." *In:* Restoration of Lakes and Inland Waters. U.S. Environmental Protection Agency. EPA 440/5-81-001.

Gasperino, A.F. and R.A. Soltero, 1980. Restoration of Medical Lake: Final Report. Battelle, Pacific Northwest Laboratories, Richland, WA. 165 pp.

Huntamer, D. and C. Smith, 1989. Laboratory User's Manual. Washington State Department of Ecology, Manchester, WA, 139 pp.

Linsley, R.K., M.A. Kohler, J.L. Paulhus, 1975. Hydrology for Engineers. McGraw-Hill Publishers.

Lorenzen, M.W., D.J. Smith, and L.V. Kimmel, 1976. A Long-term Phosphorus Model for Lakes: Application to Lake Washington. In: Modeling Biochemical Processes in Aquatic Ecosystems, R.P. Canale, Ed. Ann Arbor Science Publishers, Inc.

Mancini, J.L., G.G. Kaufman, P.A. Mangarella, and E.D. Driscoll, 1983. Technical Guidance Manual for Performing Waste Load Allocations. Book IV: Lakes and Impoundments. Chapter 2 Eutrophication. Final Report for U.S. EPA Office of Water Regulations and Standards, Contract No. 68-01-5918.

Metcalf and Eddy, 1991. Wastewater Engineering: Treatment, Disposal, and Reuse. McGraw-Hill, Inc.

OECD (Organization for Economic Cooperation and Development), 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Final Report. OECD Cooperative Program on Monitoring of Inland Waters (Eutrophication Control), Environmental Directorate, OECD, Paris, 154 pp.

Patmont, C.R., G.J. Pelletier, E.B. Welch, D. Banton, and C.C. Ebbesmeyer, 1989. Lake Chelan Water Quality Assessment. Final Report to Washington State Department of Ecology. Contract No. C0087072.

Reckhow, K.H. and S.C. Chapra, 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers.

Welch, E.B., 1980. Ecological Effects of Wastewater. Cambridge University Press.

APPENDICES

Appendix A-1. Results from the limited Class II inspection at Plant #1.

| Sample Type | Date | Time | Sampler | Lab | Flow (MGD) | Temp. (°C) | pH (S.U.) | Cond. (μmhos/cm) | D.O. (mg/L) | D.O. (% Sat.) | TRC (mg/L) | FC (cfu/100 mL) | TSS (mg/L) | BOD-5 (mg/L) | TOC (mg/L) | TP (mg/L) | TN (mg/L) | NH3-N (mg/L) | NO3+NO2 (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANT #1 | | | | | | | | | | | | | | | | | | | |
| Influent Comp. | 8/29/90 | 0900 | Ecol. | Ecol. | - | - | - | - | - | - | - | - | 161 | 198 | 118.0 | 6.00 | 16.29 | 11.11 | 0.015 |
| | | | Ecol. | WTP | - | - | - | - | - | - | - | - | 48 | 251 | - | - | - | - | - |
| | | | WTP | WTP | - | - | - | - | - | - | - | - | 20 | 163 | - | - | - | - | - |
| | | | WTP | Ecol. | - | - | - | - | - | - | - | - | 133 | 133 | - | - | - | - | - |
| Effluent Comp. | 8/29/90 | 0915 | Ecol. | Ecol. | - | - | - | - | - | - | - | - | 6 | 10 | 28.7 | 5.50 | 2.74 | 1.70 | 0.900 |
| | | | Ecol. | WTP | - | - | - | - | - | - | - | - | 2 | 14 | - | - | - | - | - |
| | | | WTP | WTP | 0.151 | - | - | - | - | - | - | - | 1 | 11 | - | - | - | - | - |
| | | | WTP | Ecol. | - | - | - | - | - | - | - | - | 7 | 7 | - | - | - | - | - |
| Effluent Grab | 8/28/90 | 1030 | Ecol. | Ecol. | 0.142 | 17.9 | 6.7 | 800 | 4.5 | 47 | 0.4 | - | - | - | - | - | - | - | - |
| | 8/29/90 | 0825 | Ecol. | Ecol. | 0.123 | 17.1 | 7.6 | 795 | 3.2 | 33 | 0.7 | 3 U | 5 | 6 | 27.1 | 4.80 | 2.15 | 2.16 | 0.058 |
| | | 1425 | Ecol. | Ecol. | - | 17.7 | 7.2 | 835 | 3.4 | 36 | 0.3 | 9 | 7 | 7 | - | - | - | - | - |
| Effluent Comp. | 9/8/90 | 1000 | WTP | Ecol. | 0.123 | - | - | - | - | - | - | - | - | - | - | 6.32 | 4.87 | - | - |
| | 9/22/90 | 1100 | WTP | Ecol. | 0.090 | - | - | - | - | - | - | - | - | - | - | 6.21 | 4.07 | - | - |
| | 10/4/90 | 1230 | WTP | Ecol. | 0.141 | - | - | - | - | - | - | - | - | - | - | 6.59 | 2.34 | - | - |
| Influent Comp. | 10/31/90 | 0945 | Ecol. | Ecol. | - | - | - | - | - | - | - | - | 76 | 180 | 79.1 | 4.08 | 4.79 | 4.55 | 0.498 |
| Effluent Comp. | 10/31/90 | 1000 | Ecol. | Ecol. | 0.187 | - | - | - | - | - | - | - | 5 | 13 J | 23.5 | 5.69 | 5.62 | 3.96 | 1.640 |
| Effluent Grab | 10/30/90 | 1100 | Ecol. | Ecol. | 0.172 | 10.0 | 7.8 | 920 | 6.9 | 61 | 1.0 | 13100 | - | - | - | - | - | - | - |
| | 10/31/90 | 1215 | Ecol. | Ecol. | - | 10.1 | 7.9 | 900 | 6.7 | 59 | 1.0 | 3 U | 5 | 12 J | 34.2 | 5.69 | 5.69 | 3.63 | 1.920 |

Repl = Replicate sample

J = Estimated value; may not be accurate

U = Analyte not detected. The value given is the sample detection limit.

Appendix A-2. Results from the limited Class II inspection at Plant #2.

| Sample Type | Date | Time | Sampler | Lab | Flow (MGD) | Temp. (°C) | pH (S.U.) | Cond. (μmhos/cm) | D.O. (mg/L) | D.O. (% Sat.) | TRC (mg/L) | FC (cfu/100 mL) | TSS (mg/L) | BOD-5 (mg/L) | TOC (mg/L) | TP (mg/L) | TN (mg/L) | NH3-N (mg/L) | NO3+NO2 (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANT #2 | | | | | | | | | | | | | | | | | | | |
| Influent Comp. | 8/29/90 | 1055 | Ecol. | Ecol. | - | - | - | - | - | - | - | - | 104 | 184 | 107.0 | 4.10 | 16.61 | 11.40 | 0.067 |
| | | | Ecol. | WTP | - | - | - | - | - | - | - | - | 32 | 263 | - | - | - | - | - |
| | | | WTP | WTP | - | - | - | - | - | - | - | - | 24 | 316 | - | - | - | - | - |
| | | | WTP | Ecol. | - | - | - | - | - | - | - | - | 152 | 240 | - | - | - | - | - |
| Effluent Comp. | 8/29/90 | 1040 | Ecol. | Ecol. | - | - | - | - | - | - | - | - | 36 | 34 | 54.1 | 7.10 | 17.77 | 17.90 | 0.039 |
| | | | Ecol. | WTP | - | - | - | - | - | - | - | - | 4 | 40 | - | - | - | - | - |
| | | | WTP | WTP | 0.230 | - | - | - | - | - | - | - | 2 | 28 | - | - | - | - | - |
| | | | WTP | Ecol. | - | - | - | - | - | - | - | - | 52 | 30 | - | - | - | - | - |
| Effluent Grab | 8/28/90 | 0900 | Ecol. | Ecol. | 0.203 | 22.3 | 7.1 | 720 | 0.1 | 1 | 0.1 U | 2200 | - | - | - | - | - | - | - |
| | 8/29/90 | 1000 | Ecol. | Ecol. | - | 23.5 | 7.4 | 820 | 0.1 | 1 | 0.1 U | 4300 | 27 | - | 50.0 | 4.80 | 15.89 | 16.40 | 0.750 |
| | | Repl. | Ecol. | Ecol. | - | - | - | - | - | - | - | 2200 | 32 | - | 49.7 | 5.10 | 15.69 | 17.40 | 0.750 |
| Effluent Comp. | 9/8/90 | 0920 | WTP | Ecol. | 0.142 | - | - | - | - | - | - | - | - | - | - | 6.29 | 13.25 | - | - |
| | 9/22/90 | 1045 | WTP | Ecol. | 0.185 | - | - | - | - | - | - | - | - | - | - | 6.78 | 7.66 | - | - |
| | 10/5/90 | 0800 | WTP | Ecol. | 0.090 | - | - | - | - | - | - | - | - | - | - | 8.28 | 3.62 | - | - |
| Influent Comp. | 10/31/90 | 0900 | Ecol. | Ecol. | - | - | - | - | - | - | - | - | 236 | 296 | 140.0 | 7.08 | 12.48 | 12.30 | 0.411 |
| Effluent Comp. | 10/31/90 | 0915 | Ecol. | Ecol. | 0.187 | - | - | - | - | - | - | - | 38 | 43 J | 68.9 | 7.94 | 14.20 | 18.60 | 0.089 |
| Effluent Grab | 10/30/90 | 0840 | Ecol. | Ecol. | 0.187 | 16.3 | 7.3 | 810 | 0.0 | 0 | 0.1 U | 7 U | - | - | - | - | - | - | - |
| | 10/31/90 | 0820 | Ecol. | Ecol. | 0.187 | 15.8 | 7.4 | 740 | 0.4 | 4 | 0.1 U | 19600 | 28 | 34 J | 51.2 | 6.23 | 12.10 | 14.00 | 0.051 |
| | | Repl. | Ecol. | Ecol. | - | - | - | - | - | - | - | 17800 | 22 | 33 J | 52.5 | 6.14 | 11.90 | 16.20 | 0.064 |

Repl = Replicate sample

J = Estimated value; may not be accurate

U = Analyte not detected. The value given is the sample detection limit.

Appendix B. Results of water quality surveys conducted on West Medical Lake 5/23/90-10/31/90.

| Station | Date | Time | Depth (meters) | Secchi (meters) | Temp (°C) | DO (mg/L) | DO (% Sat.) | pH (S.U.) | Cond (μmhos/cm) | TRC (mg/L) | FC (cfu/100 mL) | Alk (mg/L) | TP (mg/L) | SRP (mg/L) | TN (mg/L) | NH3-N (mg/L) | NO3+NO2 (mg/L) | TOC (mg/L) | Chl. a (μg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5/23/90 | - | 0.0 | 4.5 | 14.9 | 10.4 | 103 | 8.9 | 756 | - | - | - | 2.76 * | - | 1.51 * | - | - | - | - |
| | | | 1.0 | | 14.6 | 9.4 | 92 | 9.0 | 756 | - | - | - | - | - | - | - | - | - | - |
| | | | 2.0 | | 14.2 | 8.5 | 83 | 9.0 | 757 | - | - | - | - | - | - | - | - | - | - |
| | | | 3.0 | | 14.0 | 8.1 | 79 | 9.0 | 756 | - | - | - | - | - | - | - | - | - | - |
| | | | 4.0 | | 13.6 | 7.2 | 69 | 9.0 | 758 | - | - | - | - | - | - | - | - | - | - |
| | | | 5.0 | | 13.3 | 6.5 | 62 | 9.0 | 759 | - | - | - | - | - | - | - | - | - | - |
| | | | 6.0 | | 12.9 | 4.8 | 45 | 9.0 | 760 | - | - | - | - | - | - | - | - | - | - |
| | | | 7.0 | | 11.9 | 2.4 | 22 | 8.8 | 761 | - | - | - | - | - | - | - | - | - | - |
| | | | 8.0 | | 11.0 | 0.2 | 2 | 8.7 | 773 | - | - | - | - | - | - | - | - | - | - |
| 1 | 8/22/90 | - | 0.0 | 2.0 | 21.0 | 7.2 | 81 | 9.0 | 825 | - | - | - | 1.97 * | - | 2.04 * | - | - | - | - |
| | | | 1.0 | | 20.8 | 7.4 | 83 | 9.0 | 826 | - | - | - | - | - | - | - | - | - | - |
| | | | 2.0 | | 20.7 | 7.3 | 81 | 9.0 | 825 | - | - | - | - | - | - | - | - | - | - |
| | | | 3.0 | | 20.6 | 6.7 | 75 | 9.0 | 825 | - | - | - | - | - | - | - | - | - | - |
| | | | 4.0 | | 20.5 | 5.9 | 66 | 9.0 | 826 | - | - | - | - | - | - | - | - | - | - |
| | | | 5.0 | | 20.5 | 5.5 | 61 | 9.0 | 827 | - | - | - | - | - | - | - | - | - | - |
| | | | 6.0 | | 20.4 | 5.3 | 59 | 9.0 | 827 | - | - | - | - | - | - | - | - | - | - |
| | | | 7.0 | | 20.3 | 4.9 | 54 | 9.0 | 829 | - | - | - | - | - | - | - | - | - | - |
| 1 | 8/28/90 | 1245 | 0.0 | 2.0 | 21.9 | 8.8 | 100 | 8.8 | 822 | 0.01 U | - | 333 | 2.06 | 1.6 | 1.40 | 0.22 | 0.010 U | 30.8 | 18.6 |
| | | | 1.0 | | 20.2 | 9.5 | 105 | 8.8 | 826 | - | - | - | - | - | - | - | - | - | - |
| | | | 2.0 | | 20.0 | 7.2 | 79 | 8.8 | 830 | - | - | - | - | - | - | - | - | - | - |
| | | | 3.0 | | 19.9 | 6.4 | 70 | 8.8 | 835 | - | - | 332 | 2.14 | 1.8 | 1.43 | 0.28 | 0.010 U | 31.3 | 30.0 |
| | | | Repl. | | - | - | - | - | - | - | - | 331 | 2.35 | 1.9 | 1.46 | 0.28 | 0.010 | 27.8 | - |
| | | | 4.0 | | 19.7 | 4.8 | 52 | 8.8 | 838 | - | - | - | - | - | - | - | - | - | - |
| | | | 5.0 | | 19.6 | 4.4 | 48 | 8.8 | 842 | - | - | 334 | 2.11 | 1.8 | 1.38 | 0.41 | 0.010 U | 35.7 | - |
| | | | 6.0 | | 19.4 | 2.2 | 24 | 8.7 | 847 | - | - | - | - | - | - | - | - | - | 3.1 |
| | | | 7.0 | | 19.3 | 0.4 | 4 | 8.7 | 852 | - | - | 342 | 2.56 | 2.1 | 1.71 | 0.77 | 0.010 U | 28.7 | - |
| | | | 8.0 | | 18.8 | 0.1 | 1 | 8.6 | 868 | - | - | 338 | 2.36 | 2.0 | 1.63 | 0.61 | 0.010 U | 32.8 | - |

Appendix B. (continued)

| Station | Date | Time | Depth (meters) | Secchi (meters) | Temp (°C) | DO (mg/L) | DO (% Sat.) | pH (S.U.) | Cond ($\mu$mhos/cm) | TRC (mg/L) | FC (cfu/100 mL) | Alk (mg/L) | TP (mg/L) | SRP (mg/L) | TN (mg/L) | NH3-N (mg/L) | NO3+NO2 (mg/L) | TOC (mg/L) | Chl. a ($\mu$g/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 8/28/90 | 1445 | 0.0 | 2.4 | 21.3 | 8.3 | 94 | 8.8 | 825 | 0.10 U | 3 U | 332 | 1.97 | 1.9 | 1.46 | 0.28 | 0.010 | 32.8 | 11.0 |
| | | | 1.0 | | 20.2 | 7.9 | 87 | 8.8 | 832 | - | - | - | - | - | - | - | - | - | - |
| | | | 2.0 | | 19.9 | 5.9 | 65 | 8.8 | 838 | - | - | - | - | - | - | - | - | - | - |
| | | | 3.0 | | 19.7 | 4.7 | 51 | 8.8 | 844 | - | - | 333 | 2.08 | 2.0 | 1.62 | 0.32 | 0.012 | 31.7 | 15.3 |
| | | | 4.0 | | 19.6 | 3.6 | 39 | 8.8 | 847 | - | - | - | - | - | - | - | - | - | - |
| | | | 5.0 | | 19.5 | 3.1 | 34 | 8.7 | 850 | - | - | 333 | 2.14 | 1.8 | 1.64 | 0.50 | 0.012 | 24.2 | - |
| | | | 6.0 | | 19.4 | 2.5 | 27 | 8.7 | 851 | - | - | - | - | - | - | - | - | - | 3.6 |
| | | | 7.0 | | 19.2 | 0.1 | 1 | 8.7 | 859 | - | - | 334 | 2.14 | 2.3 | 1.71 | 0.69 | 0.013 | 26.8 | - |
| | | | 8.0 | | 18.9 | 0.1 | 1 | 8.6 | 874 | - | - | 337 | 2.64 | 2.4 | 2.09 | 0.99 | 0.011 | 20.3 | - |
| A | 8/28/90 | 1535 | 0.0 | - | - | - | - | - | - | - | 3 U | - | - | - | - | - | - | - | - |
| B | 8/28/90 | 1545 | 0.0 | - | - | - | - | - | - | - | 3 U | - | - | - | - | - | - | - | - |
| C | 8/28/90 | 1550 | 0.0 | - | - | - | - | - | - | 0.1 U | 13000 | - | - | - | - | - | - | - | - |
| D | 8/28/90 | 1555 | 0.0 | - | - | - | - | - | - | - | 3 U | - | - | - | - | - | - | - | - |
| 1 | 10/30/90 | 1245 | 0.0 | 2.0 | 9.2 | 13.8 | 120 | 9.0 | 791 | 0.01 U | - | 330 | 2.55 | 2.2 | 1.76 | 0.16 | 0.039 | 17.5 | 36.0 |
| | | | 1.0 | | 9.2 | 13.5 | 117 | 9.0 | 797 | - | - | - | - | - | - | - | - | - | - |
| | | | 2.0 | | 9.1 | 13.4 | 116 | 9.0 | 802 | - | - | - | - | - | - | - | - | - | - |
| | | | 3.0 | | 9.1 | 13.3 | 115 | 9.0 | 806 | - | - | 320 | 2.45 | 2.1 | 1.89 | 0.19 | 0.036 | 19.5 | 13.0 |
| | | | 4.0 | | 9.1 | 13.3 | 115 | 9.0 | 808 | - | - | - | - | - | - | - | - | - | - |
| | | | 5.0 | | 9.1 | 13.2 | 114 | 8.9 | 810 | - | - | 330 | 2.51 | 2.2 | 1.72 | 0.18 | 0.037 | 34.0 | - |
| | | | 6.0 | | 9.1 | 13.3 | 115 | 9.0 | 812 | - | - | - | - | - | - | - | - | - | 25.4 |
| | | | 7.0 | | 9.1 | 13.2 | 114 | 9.0 | 814 | - | - | 320 | 2.52 | 2.2 | 1.83 | 0.19 | 0.037 | 31.7 | - |
| | | | Repl. | | - | - | - | - | - | - | - | 330 | 2.49 | 2.2 | 1.69 | 0.19 | 0.036 | 33.1 | - |
| | | | 8.0 | | 9.1 | 13.1 | 114 | 9.0 | 815 | - | - | 340 | 2.53 | 2.2 | 1.79 | 0.19 | 0.037 | 30.6 | - |

Appendix B. (continued)

| Station | Date | Time | Depth (meters) | Secchi (meters) | Temp (°C) | DO (mg/L) | DO (% Sat.) | pH (S.U.) | Cond ($\mu$mhos/cm) | TRC (mg/L) | FC (cfu/100 mL) | Alk (mg/L) | TP (mg/L) | SRP (mg/L) | TN (mg/L) | NH3-N (mg/L) | NO3+NO2 (mg/L) | TOC (mg/L) | Chl. a ($\mu$g/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 10/30/90 | 1340 | 0.0 | 1.8 | 9.0 | 13.3 | 115 | 9.0 | 791 | 0.02 | - | 320 | 2.48 | 2.1 | 1.74 | 0.24 | 0.041 | 46.4 | 36.1 |
| | | | 1.0 | | 9.0 | 13.3 | 115 | 9.0 | 798 | - | - | - | - | - | - | - | - | - | - |
| | | | 2.0 | | 9.0 | 13.2 | 114 | 9.0 | 803 | - | - | - | - | - | - | - | - | - | - |
| | | | 3.0 | | 9.0 | 13.1 | 113 | 9.0 | 805 | - | - | 330 | 2.47 | 2.2 | 1.72 | 0.20 | 0.038 | 34.5 | 41.1 |
| | | | 4.0 | | 9.0 | 13.0 | 112 | 9.0 | 808 | - | - | - | - | - | - | - | - | - | - |
| | | | 5.0 | | 9.0 | 13.1 | 113 | 9.0 | 812 | - | - | 320 | 2.48 | 2.2 | 1.69 | 0.20 | 0.039 | 33.3 | - |
| | | | 6.0 | | 9.0 | 13.0 | 112 | 9.0 | 814 | - | - | - | - | - | - | - | - | - | 38.6 |
| | | | 7.0 | | 9.0 | 13.0 | 112 | 9.0 | 817 | - | - | 320 | 2.37 | 2.1 | 1.64 | 0.18 | 0.035 | 31.5 | - |
| | | | 8.0 | | 9.0 | 12.9 | 112 | 9.0 | 818 | - | - | 330 | 2.39 | 2.1 | 1.61 | 0.20 | 0.035 | 25.8 | - |
| | | | Blank | | - | - | - | - | - | - | - | 1 | 0.31 | 0.01 | 0.18 | 0.01 | 0.010 | 0.5 | - |
| A | 10/30/90 | 1415 | 0.0 | - | - | - | - | - | - | - | 1 U | - | - | - | - | - | - | - | - |
| B | 10/30/90 | 1410 | 0.0 | - | - | - | - | - | - | 0.02 | 1 U | - | - | - | - | - | - | - | - |
| C | 10/30/90 | 1405 | 0.0 | - | - | - | - | - | - | 0.01 U | 930 | - | - | - | - | - | - | - | - |
| D | 10/30/90 | 1335 | 0.0 | - | - | - | - | - | - | - | 1 U | - | - | - | - | - | - | - | - |

* = Composite of samples collected at 1,3, and 5 meters.

U = Analyte not detected. The value given is the sample detection limit.

Repl. = Replicated sample

Appendix C-1. Zooplankton species identified in zooplankton tows from West Medical Lake (8/28/90 and 10/30/90).

---

Phylum Arthropoda
- Class Crustacea
  - Subclass Brachiopoda
    - Order Cladocera
      - *Bosmina longirostris*
      - *Ceriodaphnia lacustris*
      - *Daphnia pulicaria* or *D. pulex*
  - Subclass Copepoda
    - Order Eucopepoda
      - *Cyclops bicuspidatus thomasi*
      - *Diaptomus leptopus*

Phylum Rotifera
- Class Monogononta
  - *Asplanchna sp.*
  - *Euclanis sp.*
  - *Keratella quadrata*
  - *Platyus quadracornis*
  - *Polyarthra dolicoptera*
  - *Synchaeta sp.*
  - *Trichocerca sp.*

---

Appendix C-2. Summary of zooplankton data collected at West Medical Lake.

| | August 28 | | October 30 | | |
|---|---|---|---|---|---|
| Taxanomic group | Site 1 (#/L) | Site 2 (#/L) | Site 1 (#/L) | Site 2 (#/L) | Average (#/L) |
| Cladocera | | | | | |
| *Bosmina longirostris* | 0.1 | 0.0 | 0.0 | 0.2 | 0.1 |
| *Ceriodaphnia lacustris* | 34.9 | 49.5 | 0.7 | 1.6 | 21.7 |
| *Daphnia pulicaria/pulex* | 25.6 | 11.3 | 3.9 | 4.3 | 11.3 |
| Cladocera total | 60.6 | 60.8 | 4.6 | 6.1 | 22.0 |
| | | | | | |
| Copepoda | | | | | |
| *Cyclops bicuspidatus thomasi* | 1.9 | 0.6 | 8.7 | 7.2 | 4.6 |
| *Diaptomus leptopus* | 2.8 | 0.3 | 0.3 | 0.3 | 0.9 |
| Copepoda total | 4.7 | 0.9 | 9.0 | 7.5 | 3.7 |
| | | | | | |
| Rotifera | | | | | |
| *Asplanchna sp.* | 2.6 | 2.0 | 0.8 | 0.4 | 1.5 |
| *Euclanis sp.* | 3.6 | 0.9 | 0.1 | 0.0 | 1.2 |
| *Keratella quadrata* | 2.2 | 0.6 | 143.9 | 132.5 | 69.8 |
| *Polyarthra dolicoptera* | 0.1 | 0.0 | 3.2 | 5.7 | 2.3 |
| *Synchaeta sp.* | 0.0 | 0.0 | 0.2 | 0.0 | 0.1 |
| Rotifera total | 8.5 | 3.5 | 148.2 | 138.6 | 49.8 |

Appendix D-1. Synoptic list of phytoplankton identified in euphotic zone samples from West Medical Lake (8/28/90 and 10/30/90).

---

Class Chlorophyceae (greens)
- *Ankistrodesmus falcatus*
- *Characium* sp.
- *Chlamydomonas* sp.
- *Oocystis lacustris*
- *Pediastrum duplex*
- *Scenedesmus acuminatus*

Class Cyanophyceae (blue-greens)
- *Aphanizomenon flos-aquae*
- *Microcystis aeruginosa*

Class Cryptophyceae (cryptomonads)
- *Cryptomonas erosa*
- *Rhodomonas minuta*

Class Chrysophyceae (golden-browns)
- *Chrysococcus refescens*

Class Bacillariophyceae (diatoms)
- *Achnanthes minutissima*
- *Fragillaria construens venter*
- *Fragillaria crotonensis*
- *Melosira granulata*
- *Nitzschia amphibia*
- *Nitzschia fonticola*
- *Nitzschia frustulum*
- *Nitzschia palea*
- *Stephanodiscus astraea*

Appendix D-2.  Summary of phytoplankton biomass data collected at West Medical Lake

| lgal Class | August 28 Biomass (mm³/L) | % | October 30 Biomass (mm³/L) | % | Average Biomass (mm³/L) | % |
|---|---|---|---|---|---|---|
| hlorophyceae (greens) | 0.022 | 3.2 | 0.002 | 0.2 | 0.012 | 1.5 |
| yanophyceae (blue-greens) | 0.388 | 56.6 | 0.016 | 1.8 | 0.202 | 25.5 |
| ryptophyceae (crytomonads) | T | 0.0 | 0.059 | 6.6 | 0.03 | 3.8 |
| hrysophyceae (golden-browns) | T | 0.0 | T | - | T | - |
| acillariophyceae (diatoms) | 0.276 | 40.2 | 0.809 | 91.3 | 0.542 | 68.7 |
| TOTAL | 0.686 | - | 0.886 | - | 0.786 | - |

T = Trace amount